Search for Higgs decays to tau-lepton pairs at the Tevatron

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On behalf of CDF and D0 collaborations

Introduction: SM vs MSSM

SUSY extensions of Standard Model:

- Introduce symmetry bosons⇔fermions
- More than double the number of fundamental particles
- Simplest extension: Minimal Supersymmetric Standard Model

$$[u,d,c,s,t,b]_{L,R}\ [e,\mu,\tau]_{L,R}\ [\nu_e,\nu_\mu,\nu_\tau]_L \qquad [\tilde{u},\tilde{d},\tilde{c},\tilde{s},\tilde{t},\tilde{b}]_{L,R}\ [\tilde{e},\tilde{\mu},\tilde{\tau}]_{L,R}\ [\tilde{\nu}_e,\tilde{\nu}_\mu,\tilde{\nu}_\tau]_L$$

$$g \quad W^{\pm},H^{\pm} \quad \gamma,Z,H_1^0,H_2^0 \qquad \tilde{g} \quad \tilde{\chi}^{\pm}_{1,2} \quad \tilde{\chi}^0_{1,2,3,4}$$

Many nice features come out:

- stability of Higgs mass wrt higher-order corrections
- unifications of gauge couplings
- Cold Dark Matter candidates

Overview of Higgs sector in MSSM

8 degrees of freedom ⇒ 5 physical Higgs states:

- CP-even neutral states h and H
- CP-odd neutral state A
- Charged states H^+ and H^-

} denote ϕ

Higgs masses and couplings:

- Tree level: two parameters sufficient, m_A and $\tan\beta = vev_2/vev_1$
- Higher orders: many MSSM parameters contribute

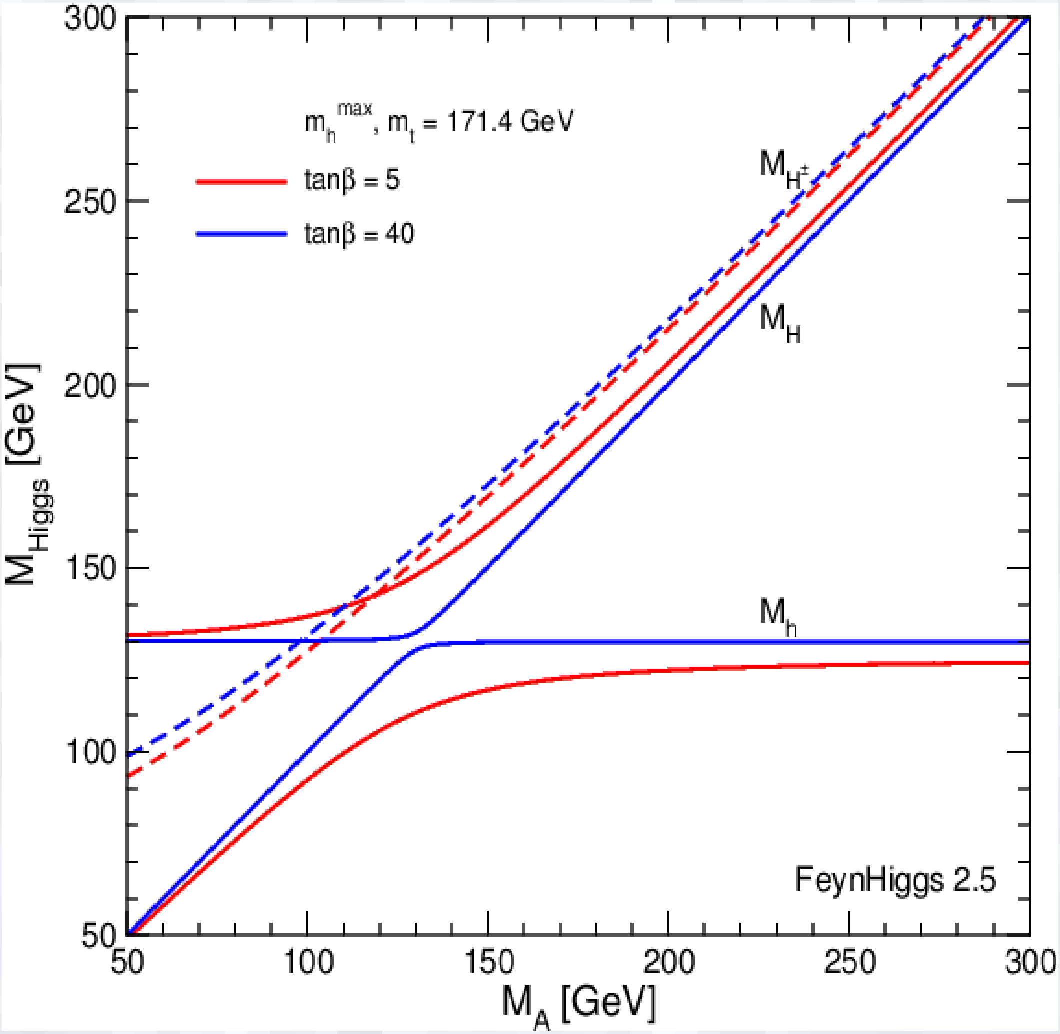
This report: search for ϕ, set mass-dependent upper limits ⇒ derive constraints on m_A and $\tan\beta$

Expectations for Higgs masses

Mass of the h

- Without corrections: $m_h < m_Z$
- With corrections:

  $m_h <$ ~135 GeV/c^2
- At low m_A, $m_h \sim m_A$

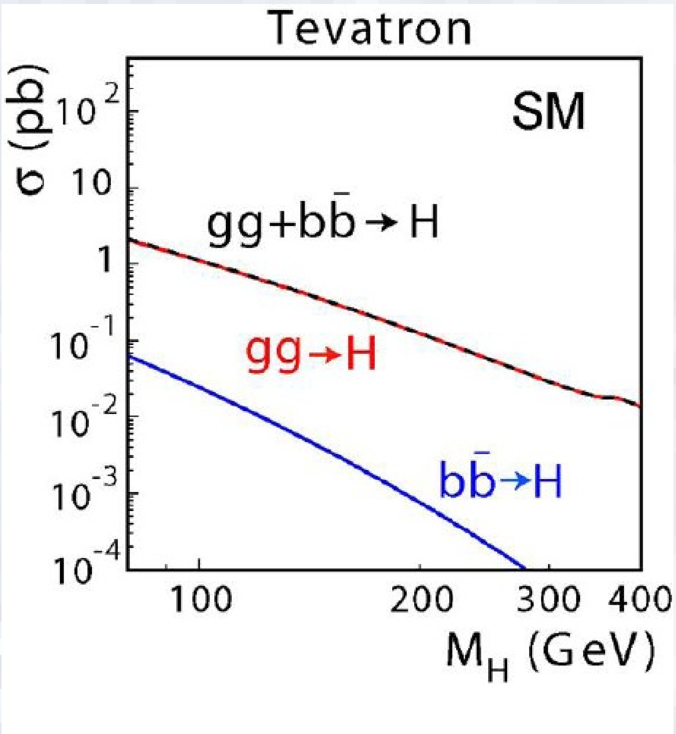


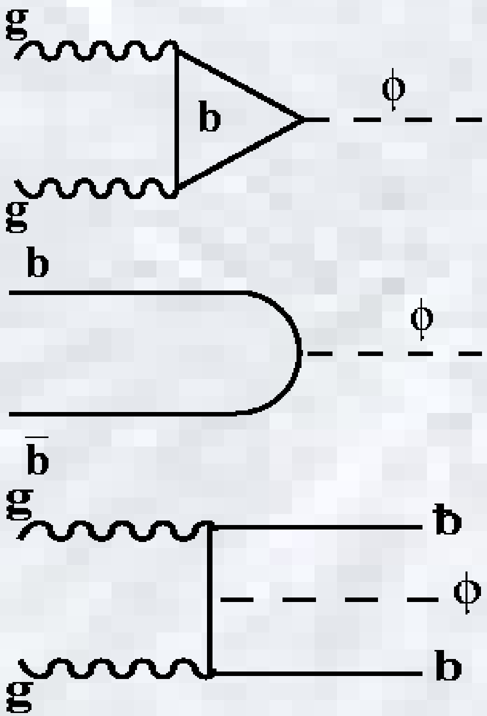
Masses of H and A

- At high m_A, large tan β:

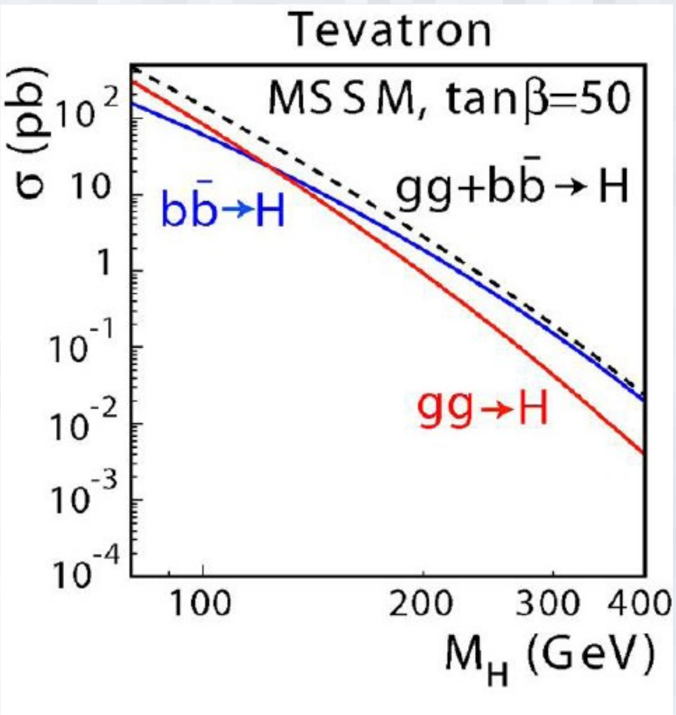
  H is almost mass degenerate with A

Production of MSSM Higgs





...more...



In MSSM compared to SM:

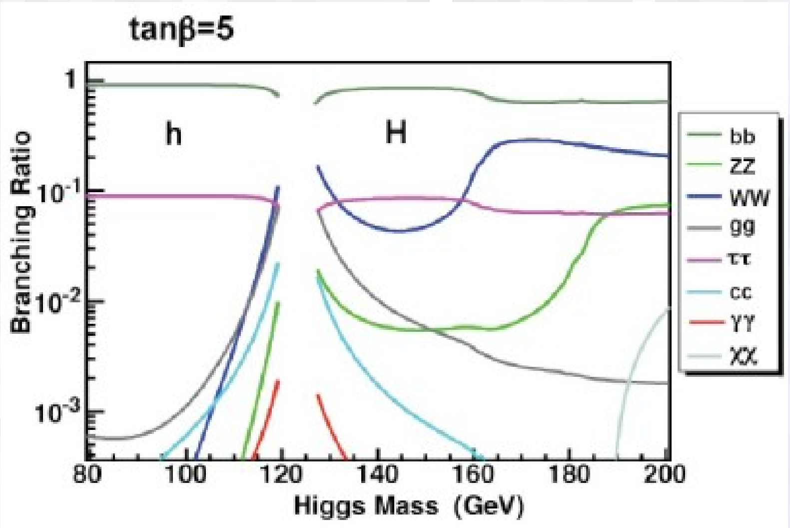
- Couplings to bottom fermions enhanced by tan β
- Cross-sections enhanced by $\tan^2 \beta$
- MSSM Higgs might be within reach for Tevatron!

Decays of neutral MSSM Higgs

Neutral Higgs decays:

$\phi \to bb$ at ~90%

$\phi \to \tau\tau$ at ~10%



Why choose $\phi \to \tau\tau$?

Difficulties with $\phi \to bb$:

- High QCD backgrounds, only $pp \to \phi + b(b)$ manageable
  - ➔ only subset of production mechanisms can be used
- Rate sensitivity to SUSY parameters
  - Production, decay strongly depend on radiative corrections

Attractive features of $\phi \to \tau\tau$:

- Lower backgrounds, all production mechanisms
- More stable wrt radiative corrections

Decays $\phi \to \tau\tau$

Consider τ decays:

- $\tau \to e \bar{\nu}_e \nu_\tau,\ \tau \to \mu \bar{\nu}_\mu \nu_\tau$ add to 36% (call them τ_e, τ_μ)
- $\tau \to hadrons + \nu_\tau$ add to 64% (call τ_{had})
  - mostly $\tau \to \pi \nu_\tau,\ \tau \to \pi \pi^0 \nu_\tau,\ \tau \to \pi \pi \pi \nu_\tau$

Choosing the best signature:

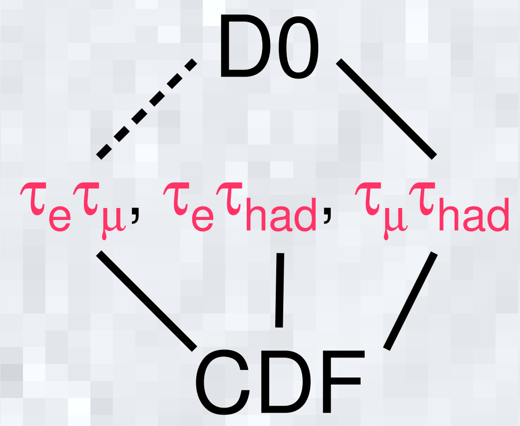
- $\tau_e \tau_e$ high background from $Z/\gamma^* \to ee$, low rate
- $\tau_\mu \tau_\mu$ high background from $Z/\gamma^* \to \mu\mu$, low rate
- $\tau_e \tau_\mu$ good! some(low) jet background, low rate
- $\tau_e \tau_{had}$ golden! High rate, low background
- $\tau_\mu \tau_{had}$ golden! High rate, low background
- $\tau_{had} \tau_{had}$ moderate jet background, highest rate

} this report

Analysis outline

I. Collect data:

- Single muon trigger at D0
- Lepton (e,μ) + track trigger at CDF
- Di-lepton trigger at CDF



II. Reconstruct τ_e, τ_μ: good lepton ID, isolation, etc

III. Reconstruct τ_{had}: low multiplicity, collimated jet

IV. Estimate backgrounds

V. Derive limits on $\sigma(pp\rightarrow\phi)\times Br(\phi\rightarrow\tau\tau)$

VI. Use standard MSSM benchmarks

$\Rightarrow$ derive limits on tan β

Background sources

Primary, irreducible background: $Z/\gamma^* \to \tau\tau$

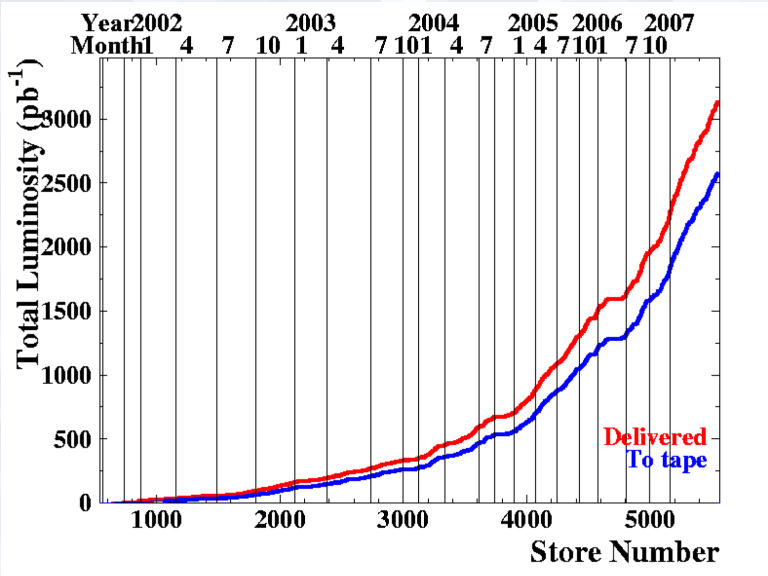
Fakes from gluon and quark jets:

- QCD multi-jet events
- W+jet(s)

Other, small, backgrounds:

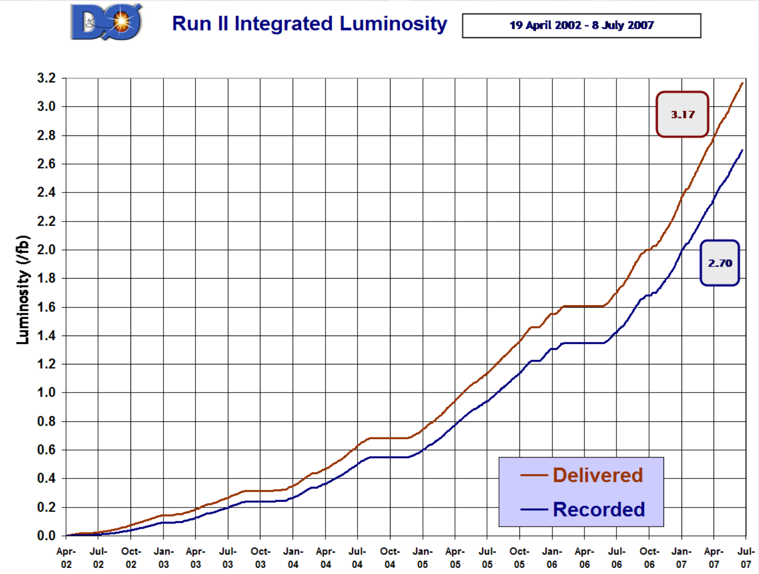
- WW, WZ, ZZ, Wγ, Zγ production
- tt production
- $Z/\gamma^* \to \mu\mu$, ee

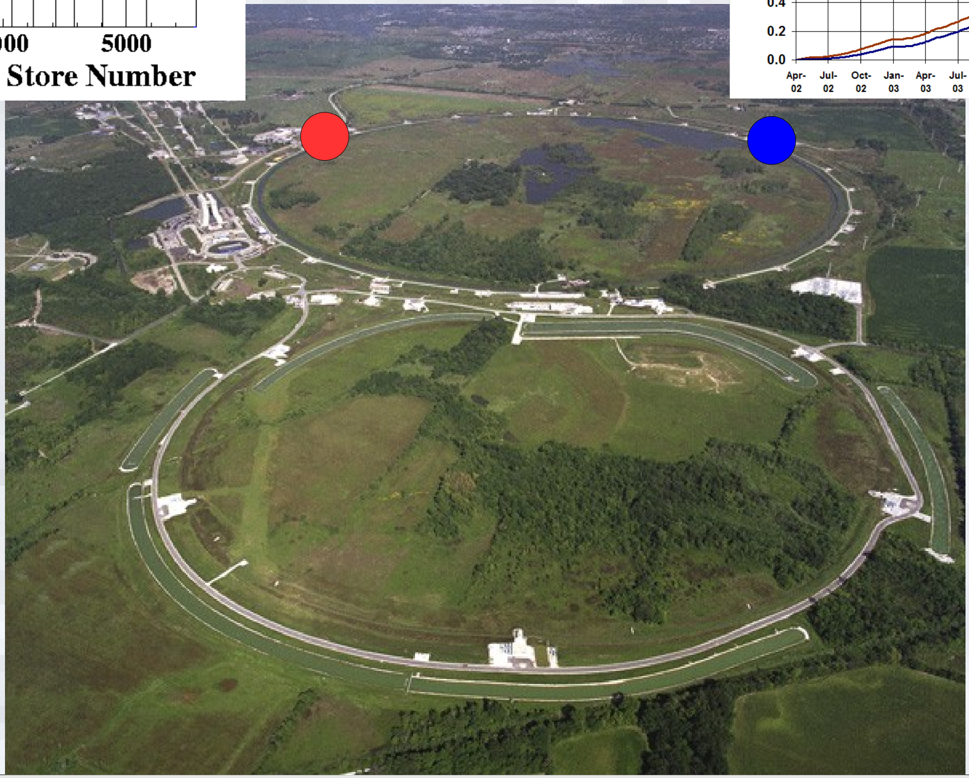
The Collider



Tevatron

$$p\bar{p} \quad @ \quad \sqrt{s}=1.96\,TeV$$





CDF

Used: 1.0 fb^{-1}

Available: >2 fb^{-1}

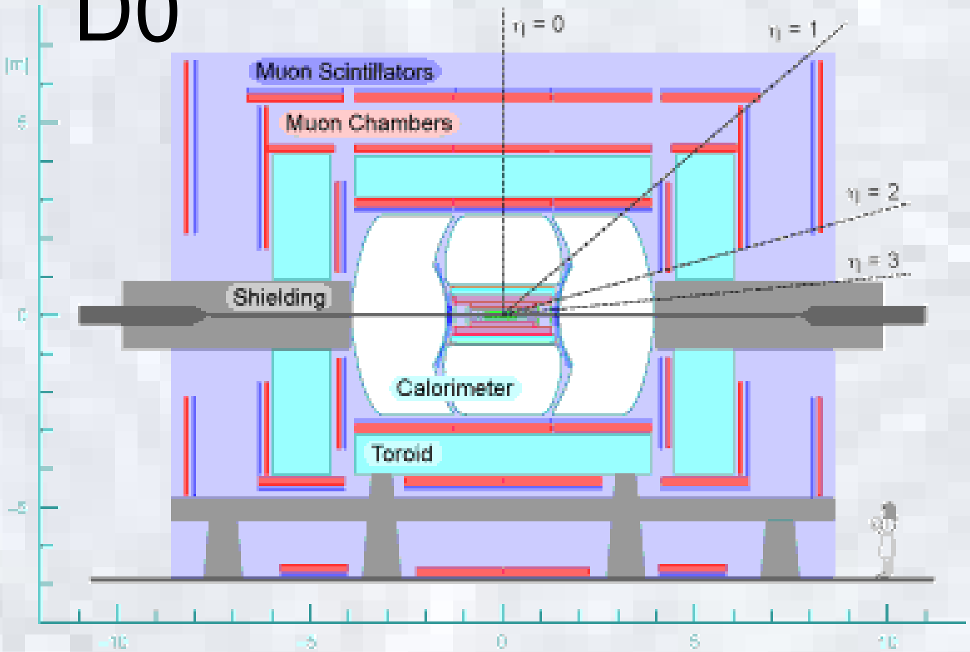
D0

Used: 1.0 fb^{-1}

Available: >2 fb^{-1}

CDF and D0 detectors

D0



Highlights:

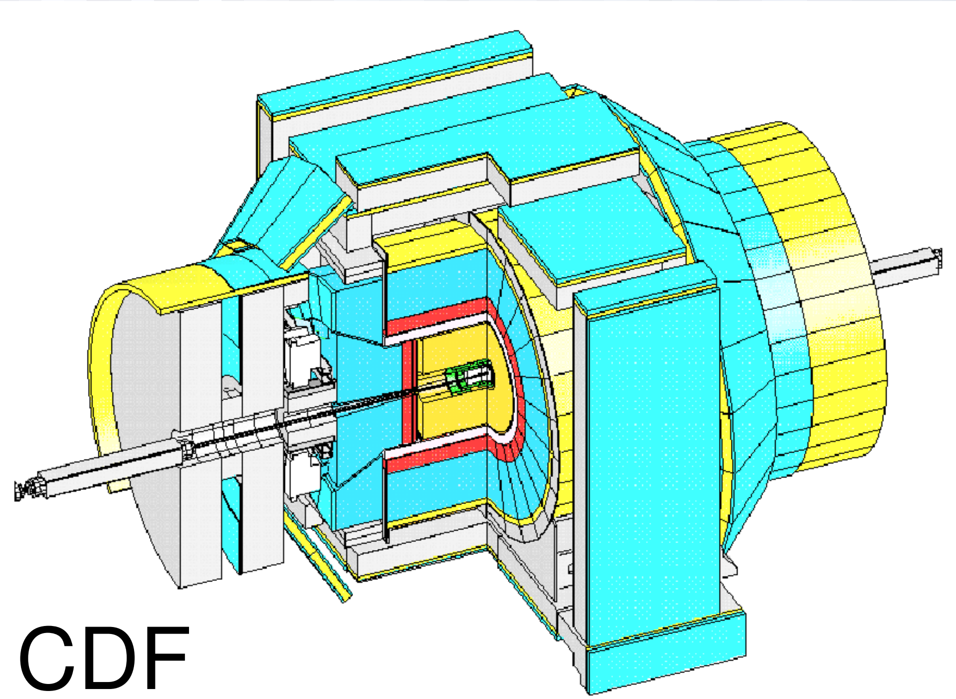
Tracker ⇒ e, μ, π tracks

Trigger ⇒ interesting events

Muon detectors ⇒ μ

EM calorimeter ⇒ e, π^0

Hadron calorimeter ⇒ E



CDF

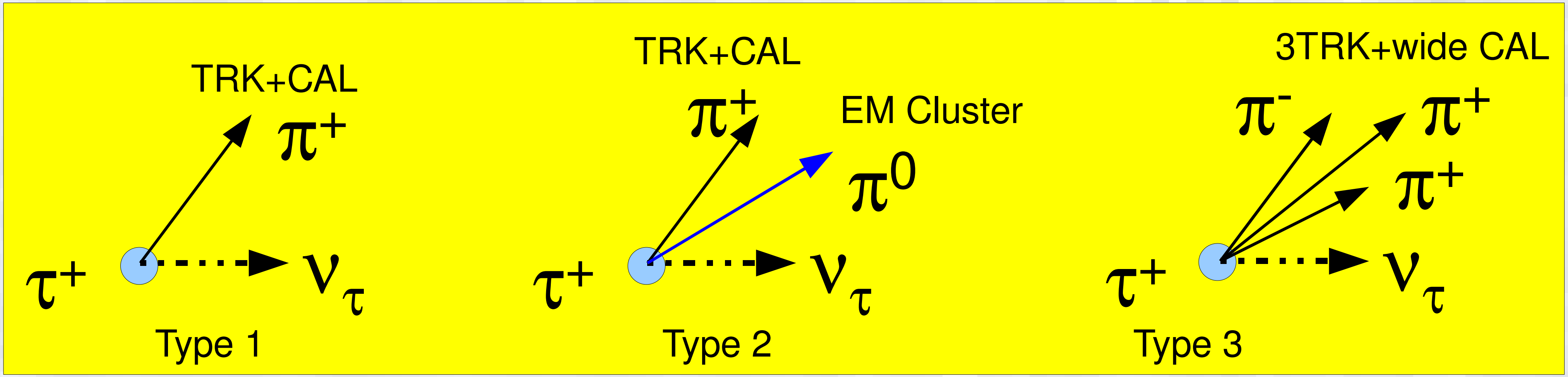
τ reconstruction

τ_{had} reconstruction:

- NN based on kinematics, CAL, etc
- Separate NN for each type
- Training: MC signal, multi-jet data bg
- Require NN>0.9 (0.95) for types 1,2 (3)

τ_{μ} reconstruction:

- Trigger μ, $P_T > 15$ GeV/c
- Isolated in CAL, tracker



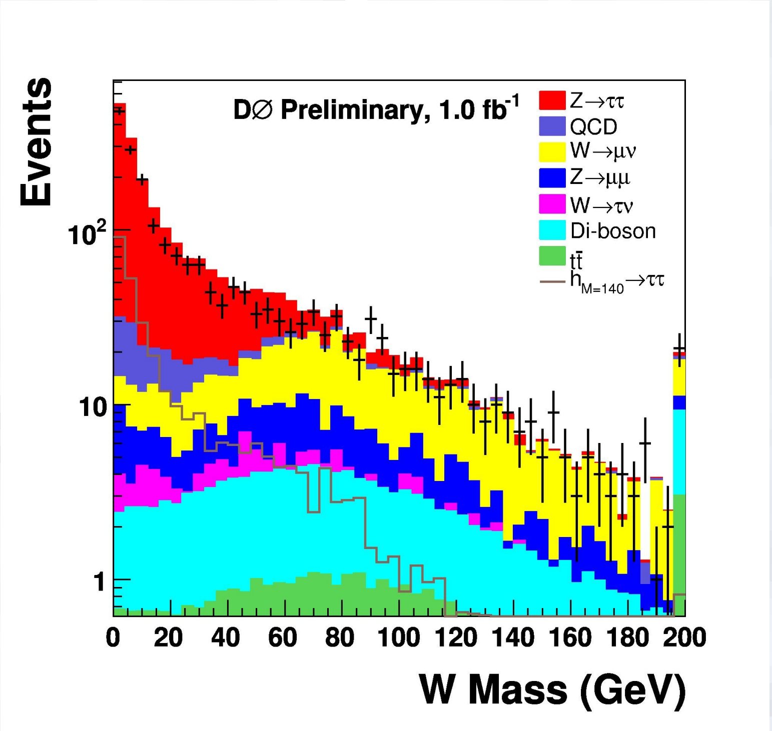
$\phi \rightarrow \tau\tau$ reconstruction

Kinematics:

- Require separation $\Delta R(\tau_\mu, \tau_{had}) > 0.5$
- W veto: $M_W < 20$ GeV/c^2

$$M_W = \sqrt{2 E^\nu E^\mu (1 - \cos \Delta\phi)}$$

- Reco $\varepsilon(\phi \rightarrow \tau\tau) = 1.4\%$ for $m_\phi = 140$ GeV/c^2



Yields: expected background, observed data

$Z \rightarrow \tau\tau$	1163 ± 27	$Z \rightarrow \mu\mu$	18 ± 3
QCD	60 ± 30	$W + jet$	33 ± 5
$t\bar{t}$	3.3 ± 0.3	$WW/WZ/ZZ$	10 ± 1

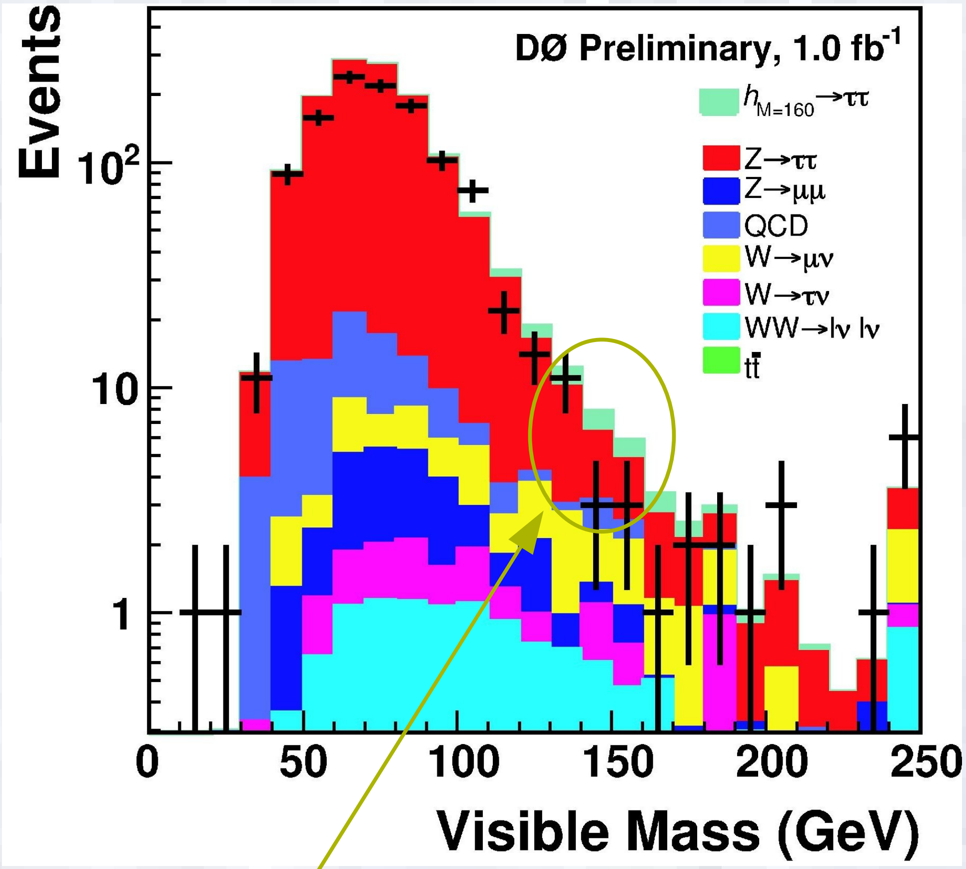
Predicted	1287 ± 130
Data	1144

Cross-section analysis

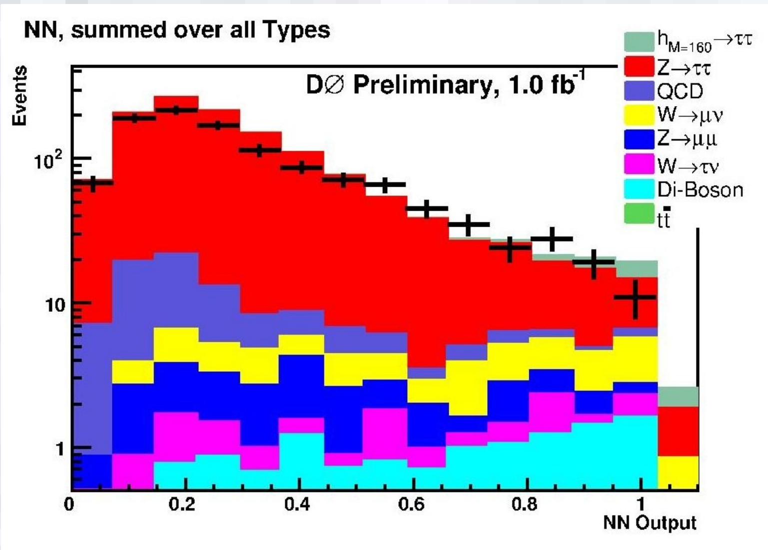
Neural network analysis:

- Use m_{vis}, p_T, η, ...
- Train on MC signal, weighted bg.
- Train at mA=90,100,...200 GeV
- Separate for each τ_{had} type

Get limits from NN distributions

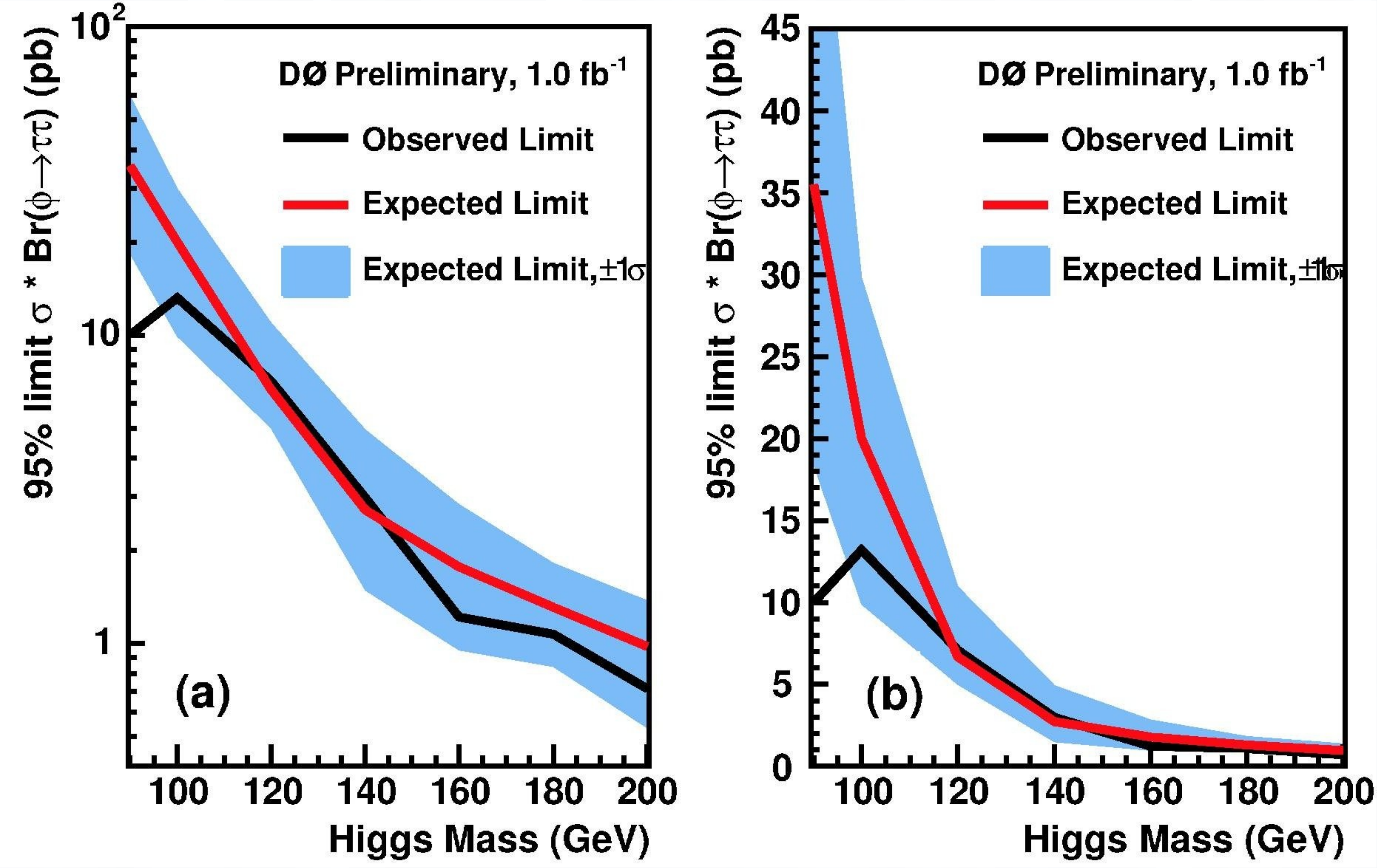


No visible excess



Consistent with background-only observation

Limits on $\sigma(pp\rightarrow\phi)\times Br(\phi\rightarrow\tau\tau)$



Result: 95% Confidence Level limits

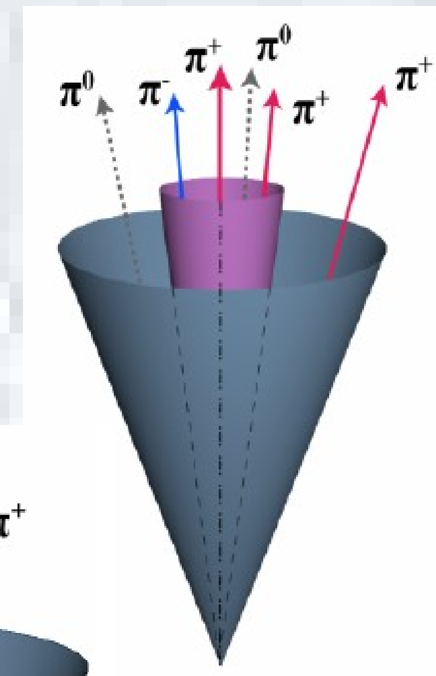
τ reconstruction

τ_{had} reconstruction:

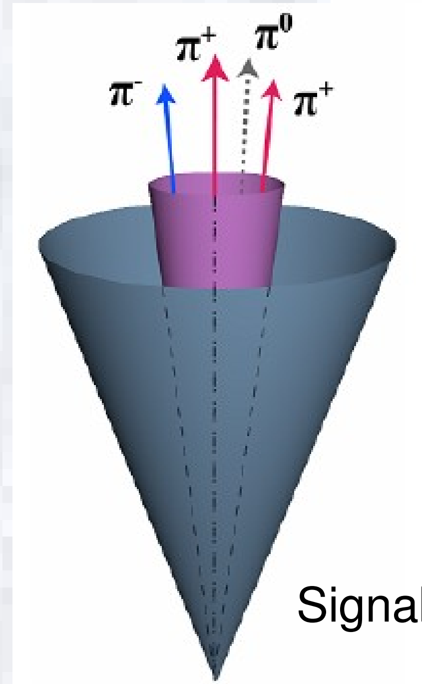
- Narrow jet, 1 or 3 tracks plus π^0's
- Optimized signal cone $\alpha_{sig} = min(10^{\circ}, \frac{5\ GeV}{E_{cl}})$
  - Seed: track p_T>6 GeV/c + ≤6 CAL towers
- Isolation annulus $\alpha_{sig} < \alpha < 30°$
  - Tracks $\sum p_T$<2 GeV/c, $\sum E_T$<1 GeV/c
  - Suppress quark, g-jets

$\tau_{e/\mu}$ reconstruction:

- Trigger lepton, isolated in CAL, tracker
- P_T >10 (6) GeV/c for $\tau_{e/\mu}\tau_{had}$ ($\tau_e\tau_\mu$)



Jet background



Signal: isolated tau

Background suppression in $\phi \to \tau\tau$

H_T cut:

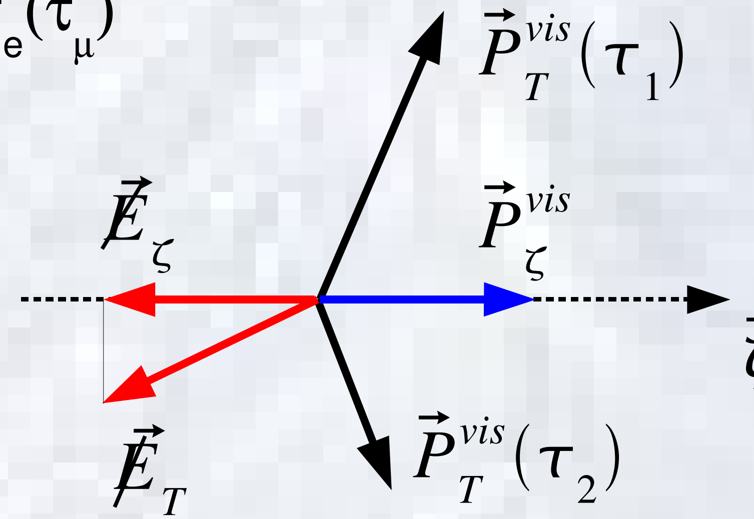
- QCD suppression
- define $H_T \equiv |p_T^{e/\mu}| + |p_T^{had}| + |\not{E}_T|$
  - H_T>55 GeV for 3-prong τ_{had}
  - H_T>50 (45) GeV for 1-prong τ_{had} vs $\tau_e(\tau_\mu)$

•Suppress $Z/\gamma^* \to \mu\mu$,ee:

- $\phi \to \tau_\mu \tau_{had}$(1prong): $|m_\phi - m_Z|>10$
- $\phi \to \tau_e \tau_{had}$(1prong): e veto

Bisection axis cuts:

- di-boson, W-jet, ttbar suppression
- $p_\zeta > 1.6 \cdot p_\zeta^{vis} - 10\,GeV$
  - ζ is bisection axis of $\vec{P}_T^{vis}(\tau_1), \vec{P}_T^{vis}(\tau_2)$
  - $p_\zeta = (\vec{p}_T(\tau_1) + \vec{p}_T(\tau_2) + \vec{\not{E}}_T) \cdot \vec{\zeta}_n$
  - $p_\zeta^{vis} = (\vec{p}_T(\tau_1) + \vec{p}_T(\tau_2)) \cdot \vec{\zeta}_n$



Yields

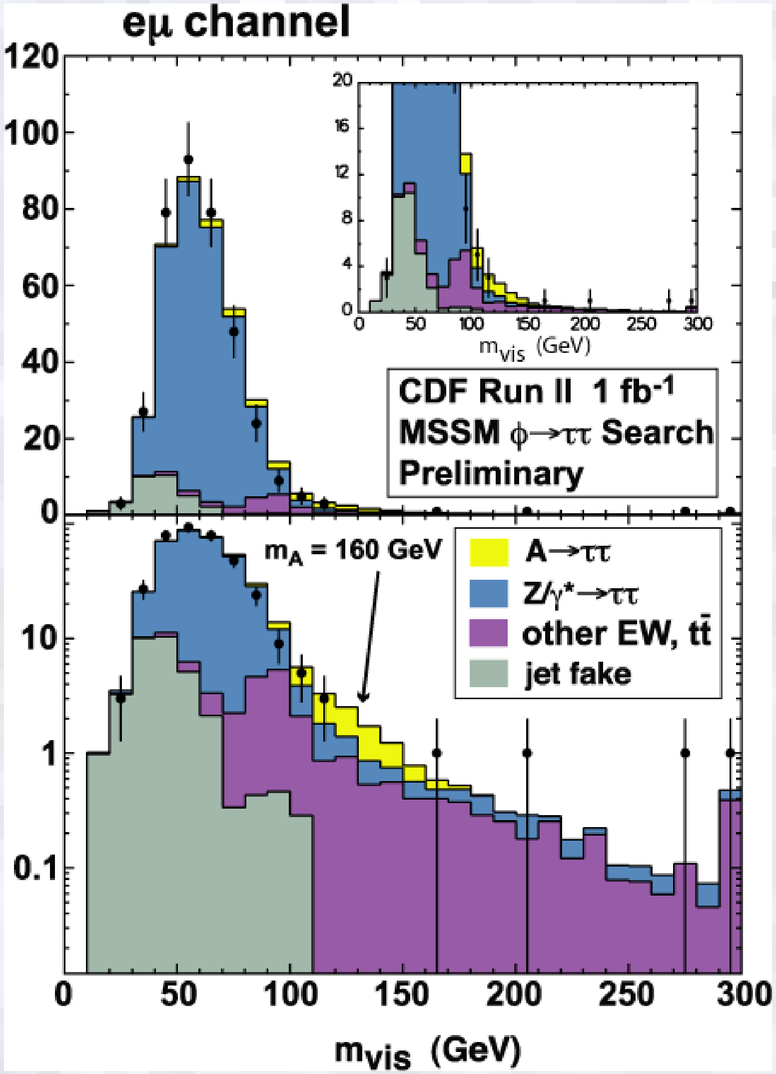
Event counts for data and expected backgrounds:

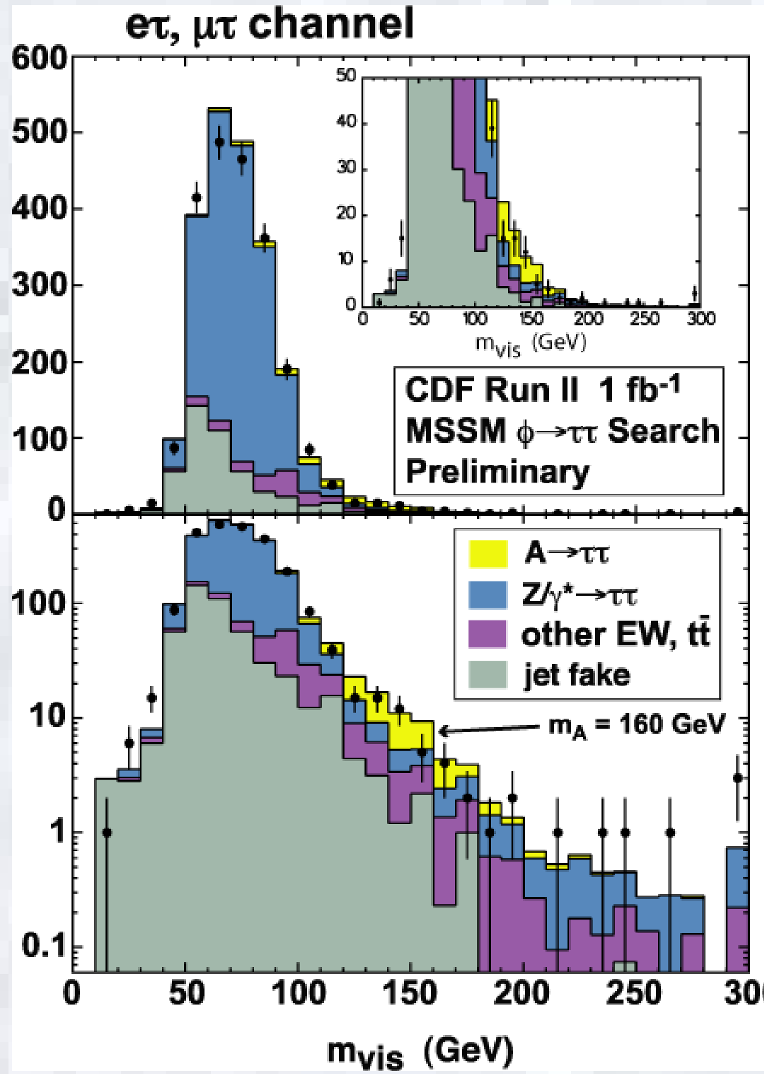
	$\tau_e\tau_{had}$	$\tau_\mu\tau_{had}$	$\tau_e\tau_\mu$
$Z\rightarrow\tau\tau$	993.0 ± 4.7	796.6 ± 4.6	312.4 ± 2.9
$Z\rightarrow ee,\mu\mu$	68.3 ± 1.9	63.2 ± 1.8	11.9 ± 0.8
$di-boson\ events$	1.5 ± 0.02	1.2 ± 0.02	6.1 ± 0.1
$t\bar{t}$	1.3 ± 0.03	1.1 ± 0.03	4.7 ± 0.07
$jet\ fakes$	333.17 ± 18.2	139.4 ± 11.4	33.5 ± 3.2

Predicted	1195.9 ± 18.9	1001.5 ± 12.5	368.6 ± 4.4
Data	1215	1000	374

Note: the CDF yields tables do not include systematic errors.

m_{vis} spectra

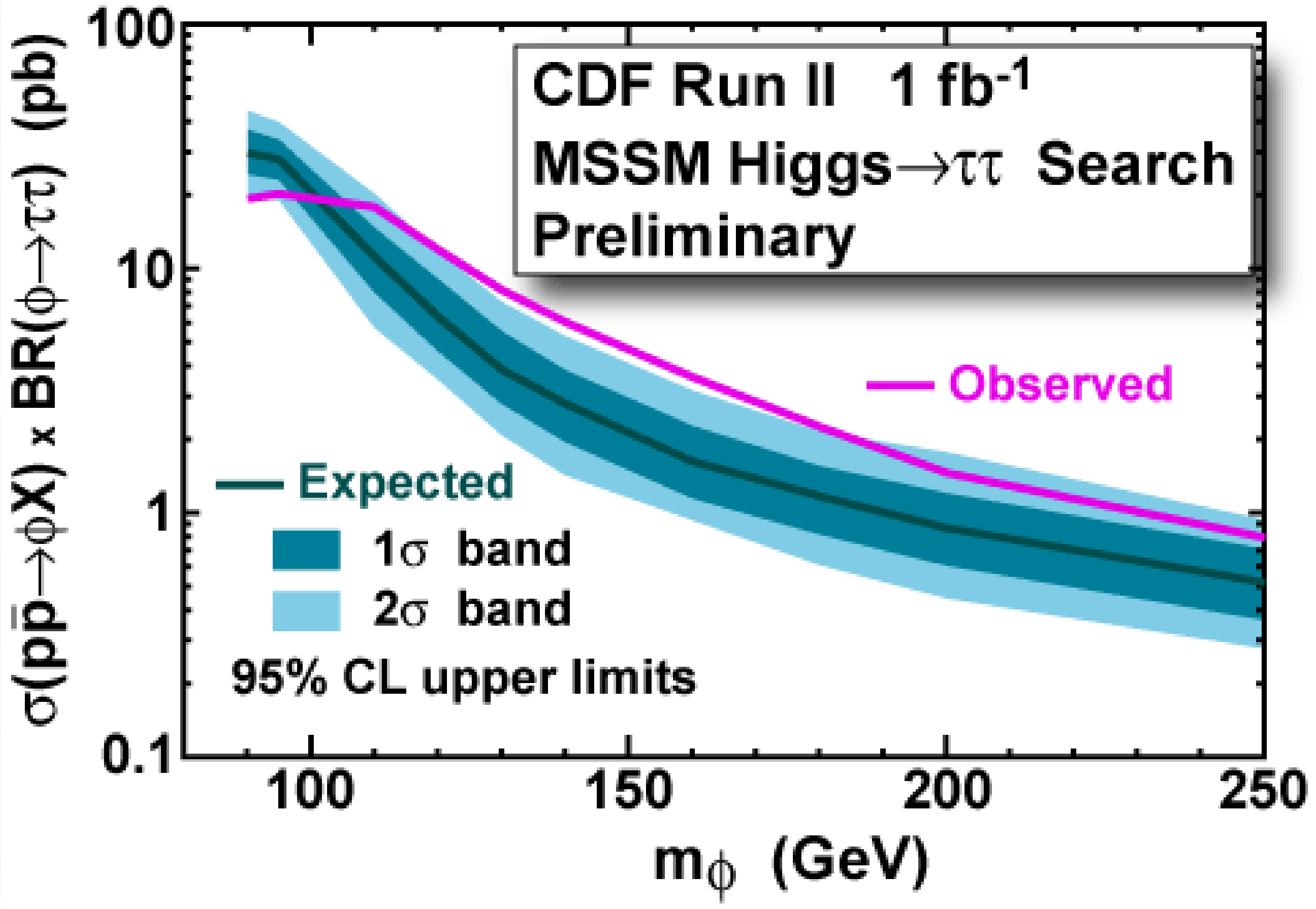




Small excess observed, statistically not significant

Consistent with background-only observation

Limits on $\sigma(pp\rightarrow\phi)\times Br(\phi\rightarrow\tau\tau)$



Result: 95% Confidence Level limits

MSSM benchmark scenarios

How to interpret $\sigma(pp \to \phi) \times Br(\phi \to \tau\tau)$ observable?

- Large phase space of MSSM parameters

$\Rightarrow$ establish indicative cases, "benchmark scenarios"

M.Carena et al, hep-ph/9912223

Some relevant parameters

μ mixing parameter of Higgs dublets

X_t mixing in stop-sector

M_2 SU(2) guagino mass parameter

$m_{\tilde{g}}$ gluino mass

M_{SUSY} scale of soft SUSY symmetry breaking

Scenario m_h^{max}: set of parameters maximizing m_h for given tan β

Scenario no-mixing: as m_h^{max}, but X_t=0

Sign of μ: try m_h^{max} and no-mixing with μ>0 and μ<0

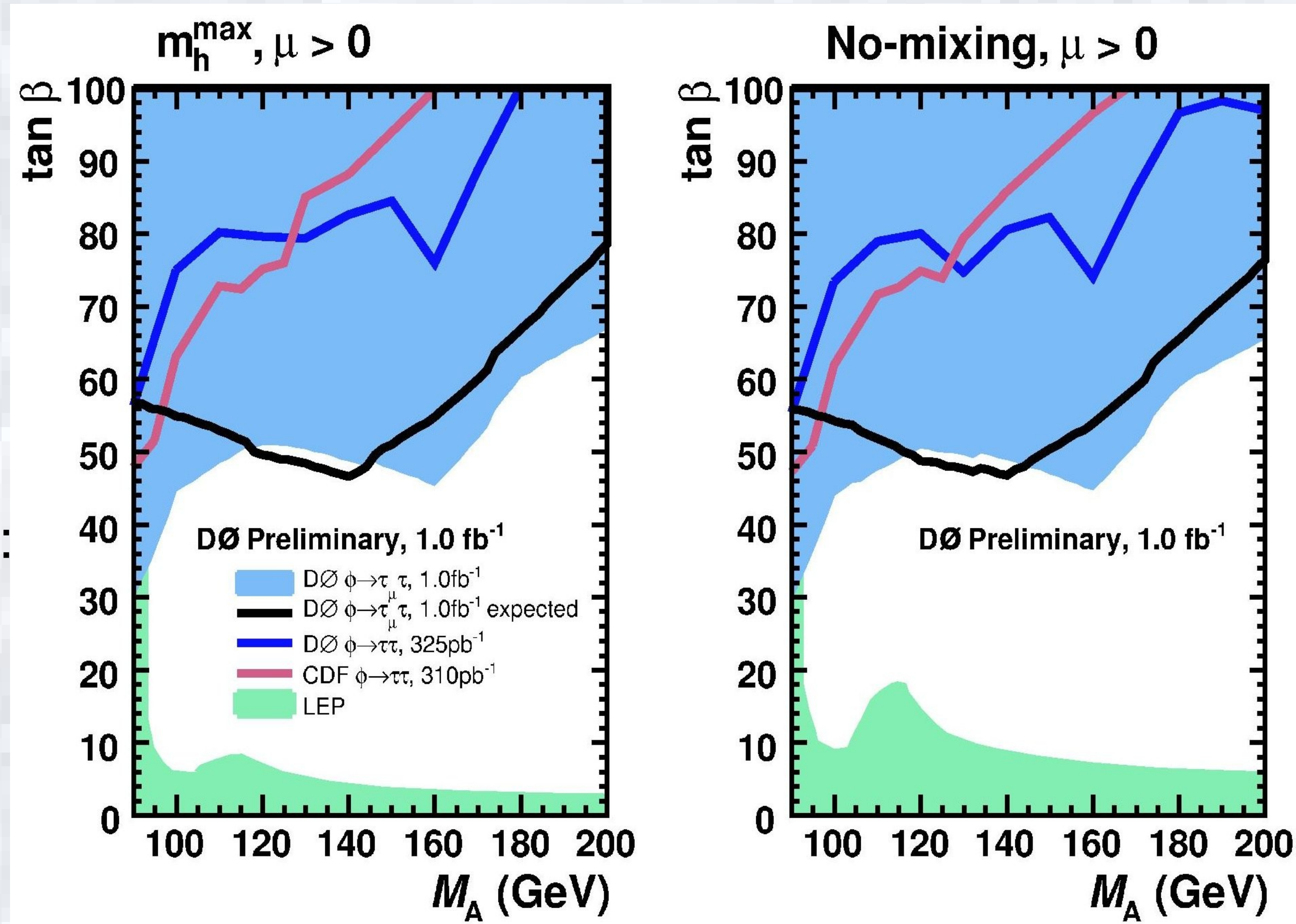
m_A vs tan β limits (μ>0) from D0

m_h^{max} scenario:

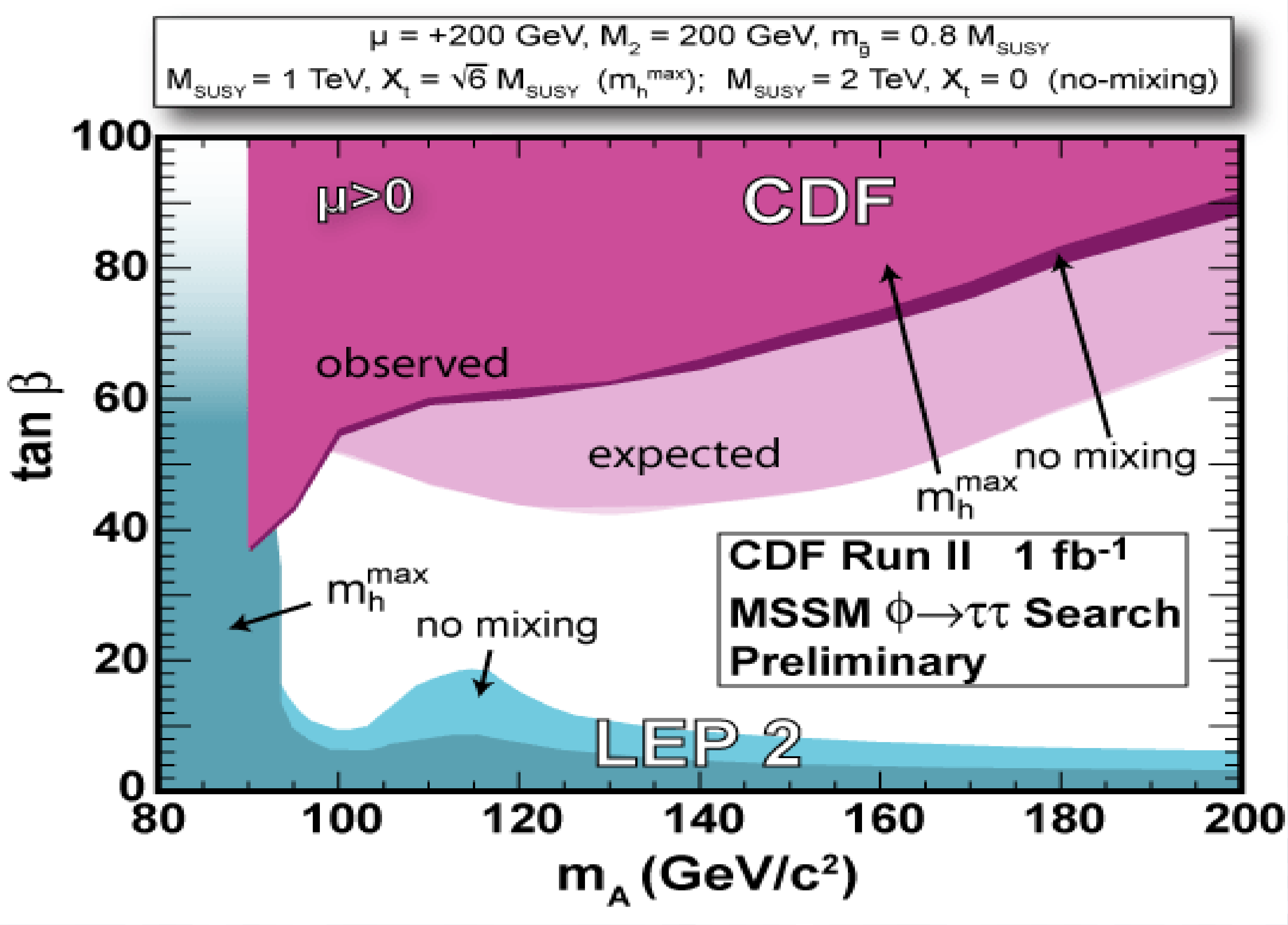
- X_t = 2 TeV
- μ = 0.2 TeV
- M_2 = 0.2 TeV
- $m_{\tilde{g}}$ = 0.8 TeV
- M_{SUSY} = 1 TeV

no-mix scenario:

- X_t = 0 TeV
- μ = 0.2 TeV
- M_2 = 0.2 TeV
- $m_{\tilde{g}}$ = 1.6 TeV
- M_{SUSY} = 2 TeV



m_A vs tan β limits (μ>0) from CDF



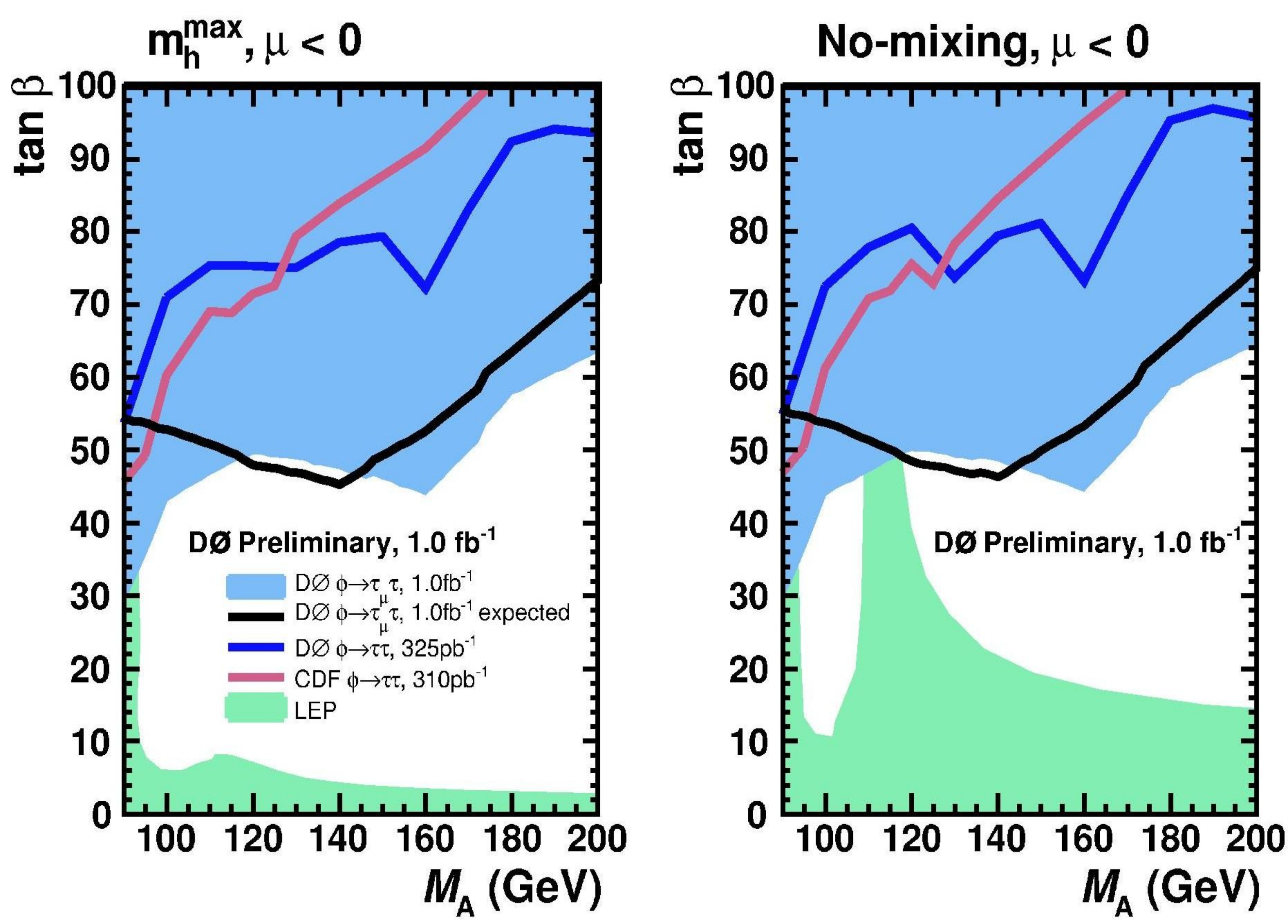
m_A vs tan β limits (μ<0) from D0

m_h^{max} scenario:

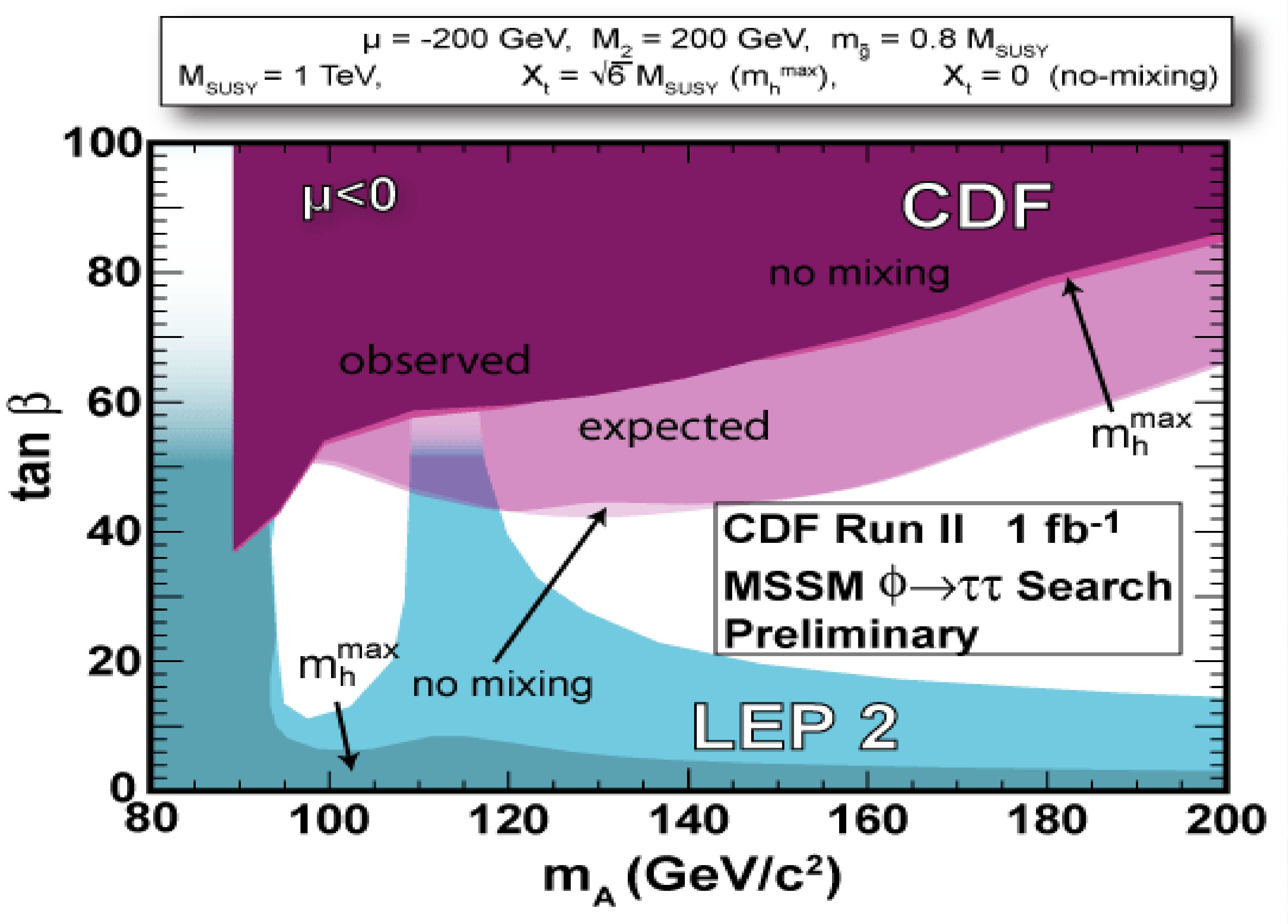
- X_t = 2 TeV
- μ = -0.2 TeV
- M_2 = 0.2 TeV
- $m_{\tilde{g}}$ = 0.8 TeV
- M_{SUSY} = 1 TeV

no-mix scenario:

- X_t = 0 TeV
- μ = -0.2 TeV
- M_2 = 0.2 TeV
- $m_{\tilde{g}}$ = 1.6 TeV
- M_{SUSY} = 2 TeV



m_A vs tan β limits (μ<0) from CDF



Conclusions

CDF and D0 imposed limits on ($\tan\beta$, m_A) plane

- excluded region is roughly $\tan\beta > 50$-60
- only slightly sensitive to benchmark scenarios

Significant additions and improvements expected:

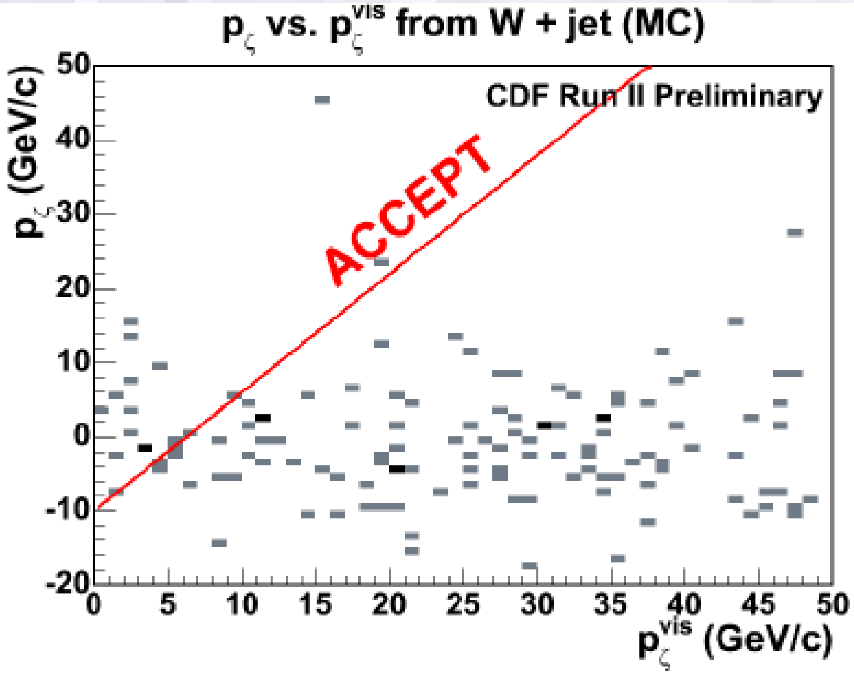
- already have x2.6 of luminosity on tape, more to come
- add other τ decay channels at D0
- analyses refinements $\Rightarrow$ increased statistical power
- combining with future $\phi \to$bbar results
- combining CDF and D0 results

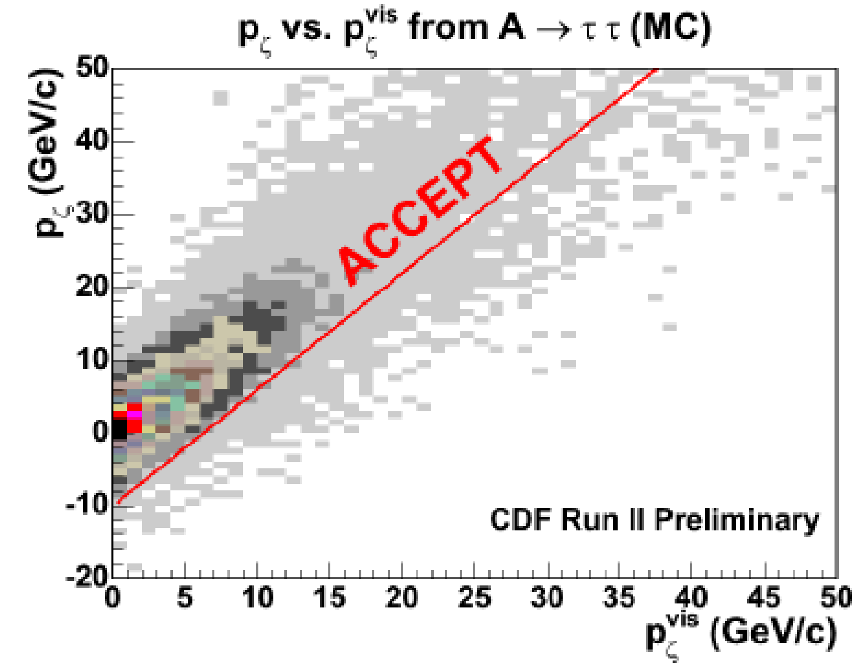
No discoveries... yet!

Backup slides

Bisection axis cut at CDF

The cut definition: $p_\zeta > 1.6 \cdot p_\zeta^{vis} - 10\,GeV$





Example of the effect of the cut for $\tau_\mu \tau_{had}$ candidate events