Taus in real data: neutral MSSM Higgs search in the tau decay channel at CDF

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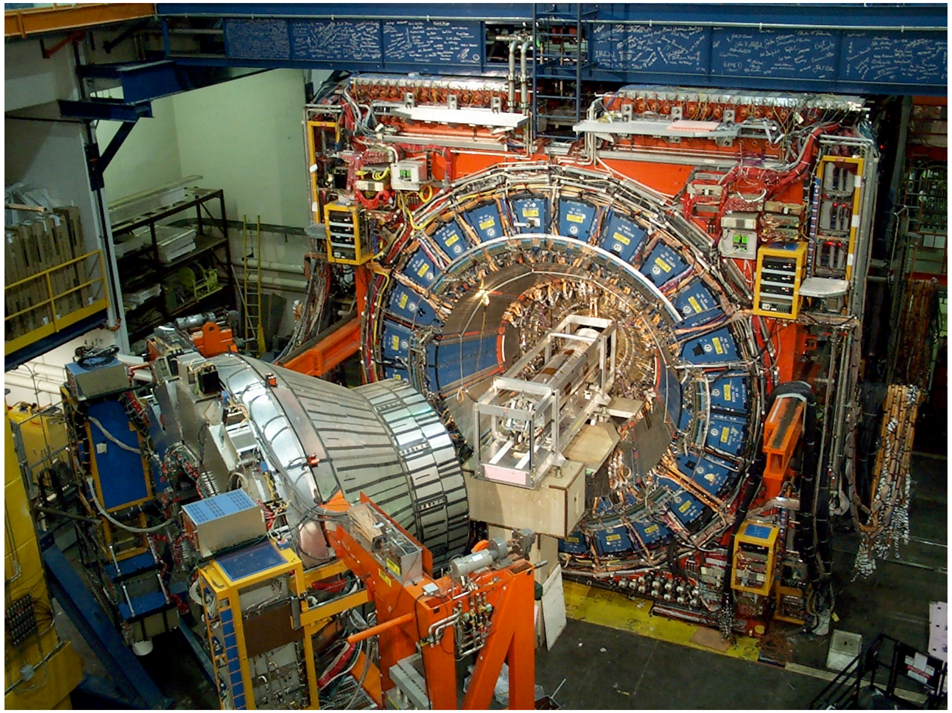
Outline

- Search motivation:
  - why MSSM and why this channel?
- The Tevatron and CDF:
  - how can our detector "see" particles?
- Analysis description
  - Data samples and trigger
  - Particle identification
  - event selection, background estimation and signal acceptance
- Observed events, fit and results
- Conclusions



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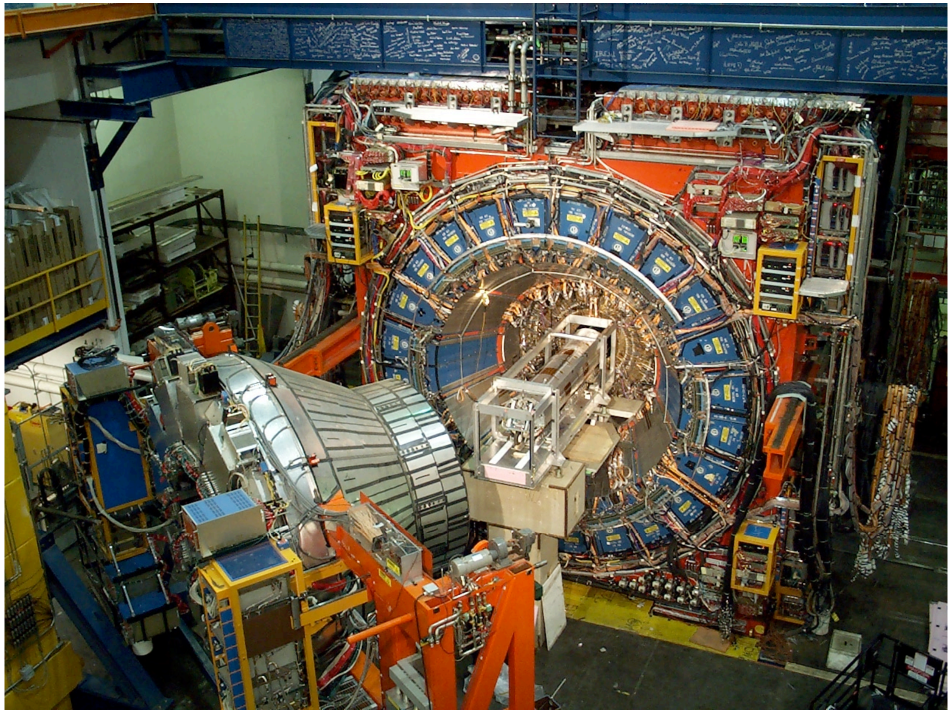
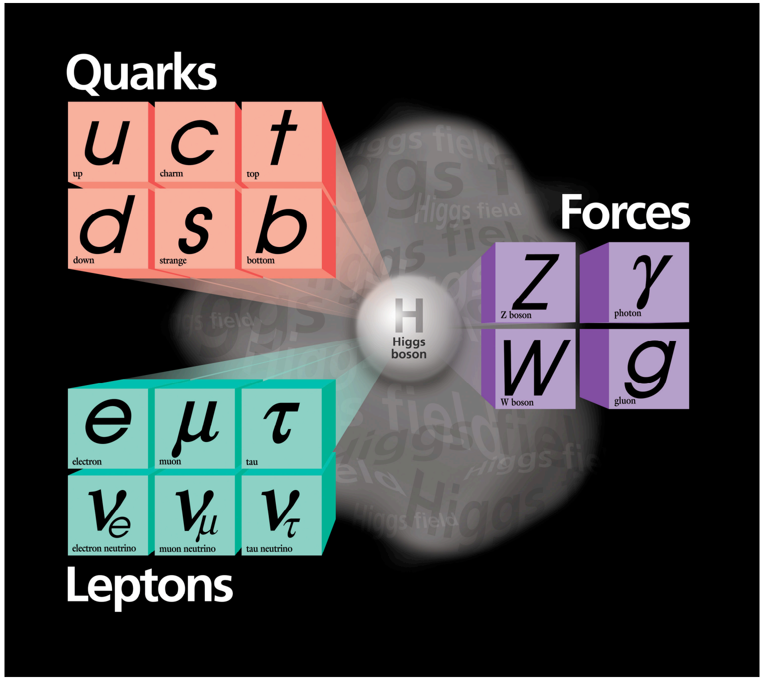
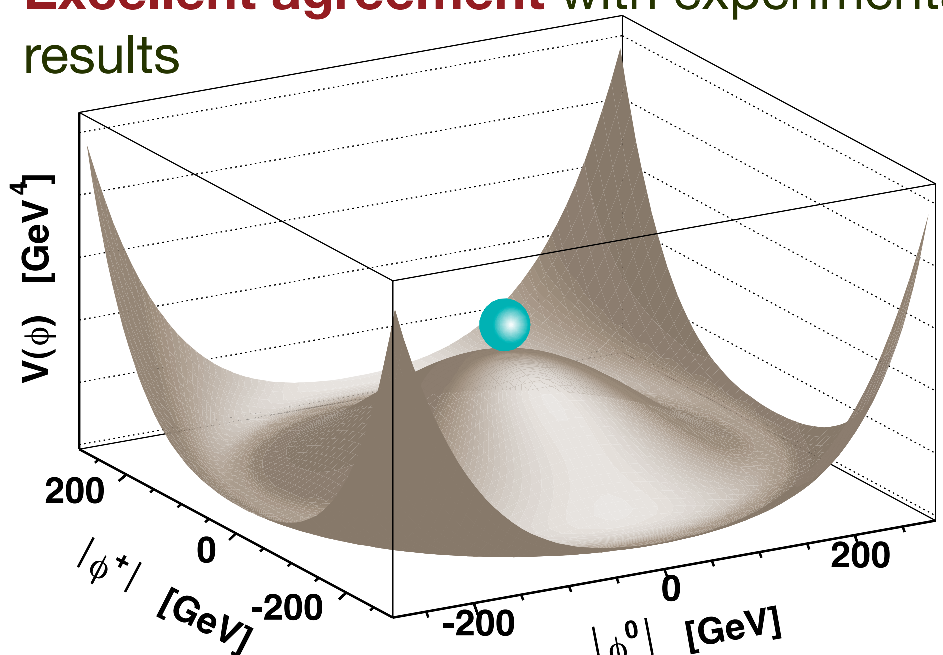


Standard Model

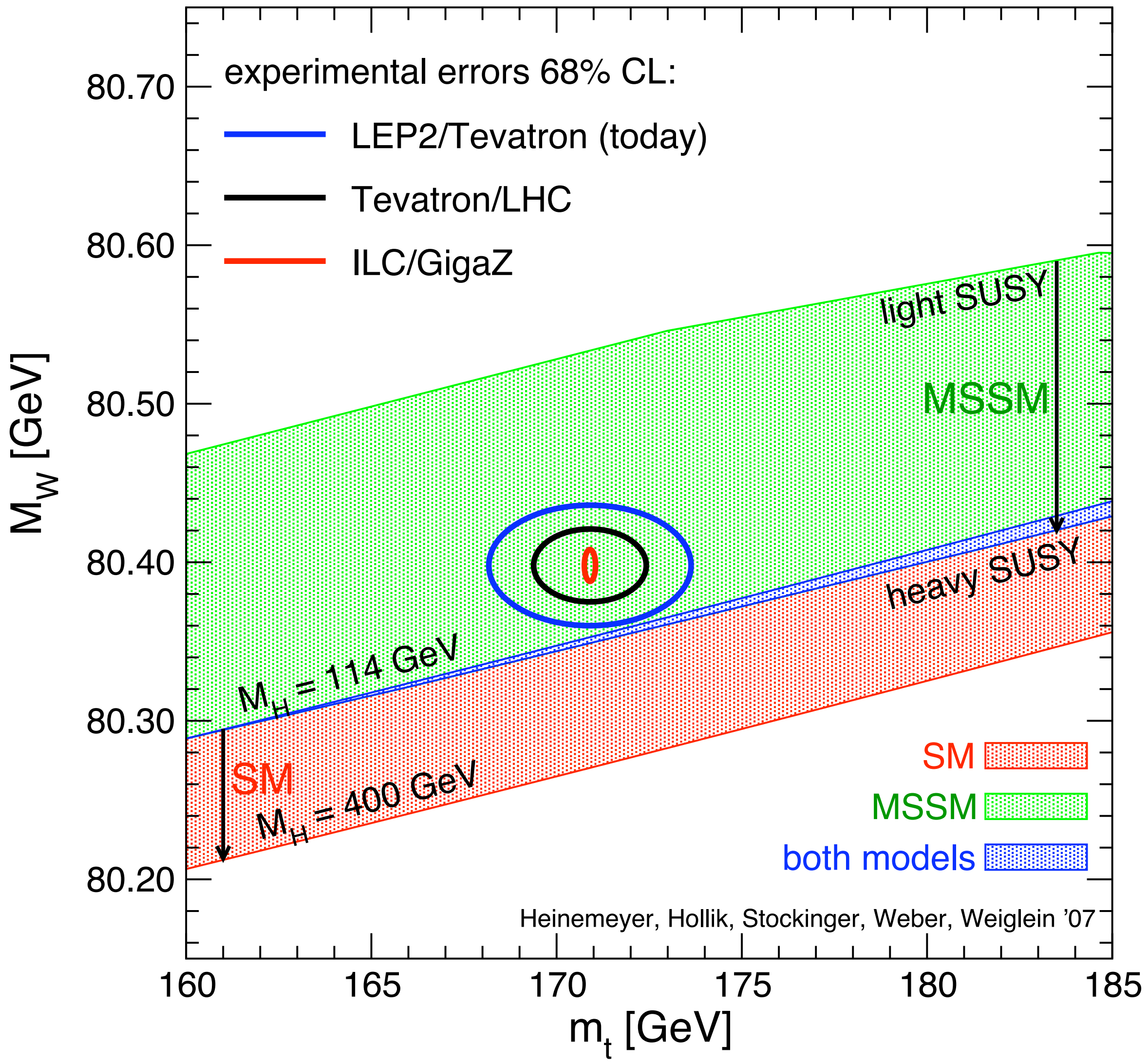


- Fundamental **particles**:
  - fermions → matter
  - bosons → interactions
- Fundamental **interactions** derive from symmetry principles
- **Excellent agreement** with experimental results



- Electroweak **symmetry breaking** mechanism hypothesized, but no experimental evidence
- **Higgs** boson: new scalar
- **No prediction** on mass from theory, but some constraints

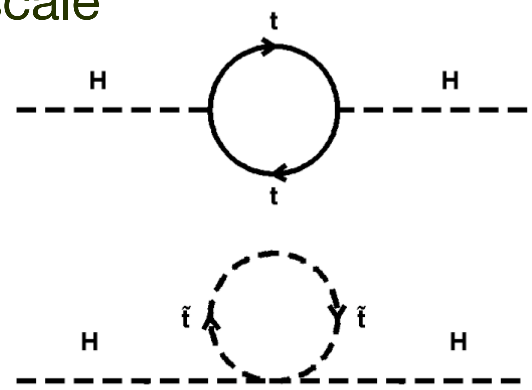
Limitations of the SM

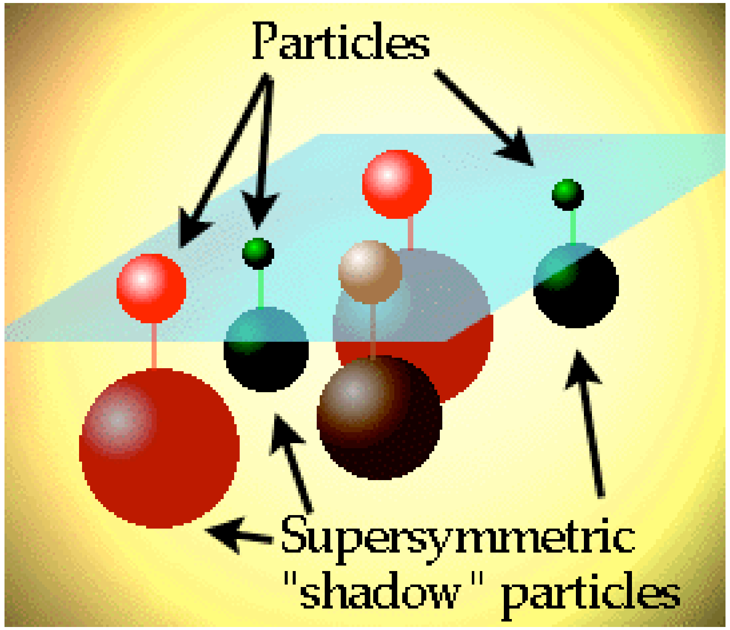


- Current electroweak fits prefer a **lighter Higgs** boson
- SM faces theoretical difficulties, like fine tuning (**hierarchy problem**, loop corrections)
- Issue solved in SUSY
- **Alternative scenarios**, like MSSM, are favored by experimental results

Supersymmetry

- **New symmetry** relates:
  - a hypothetical boson to each known fermion
  - a hypothetical fermion to each known boson
- This symmetry is broken: **new particles**
- **Fine tuning** solved naturally
- Couplings **unify** at large, 10^{16} GeV, scale

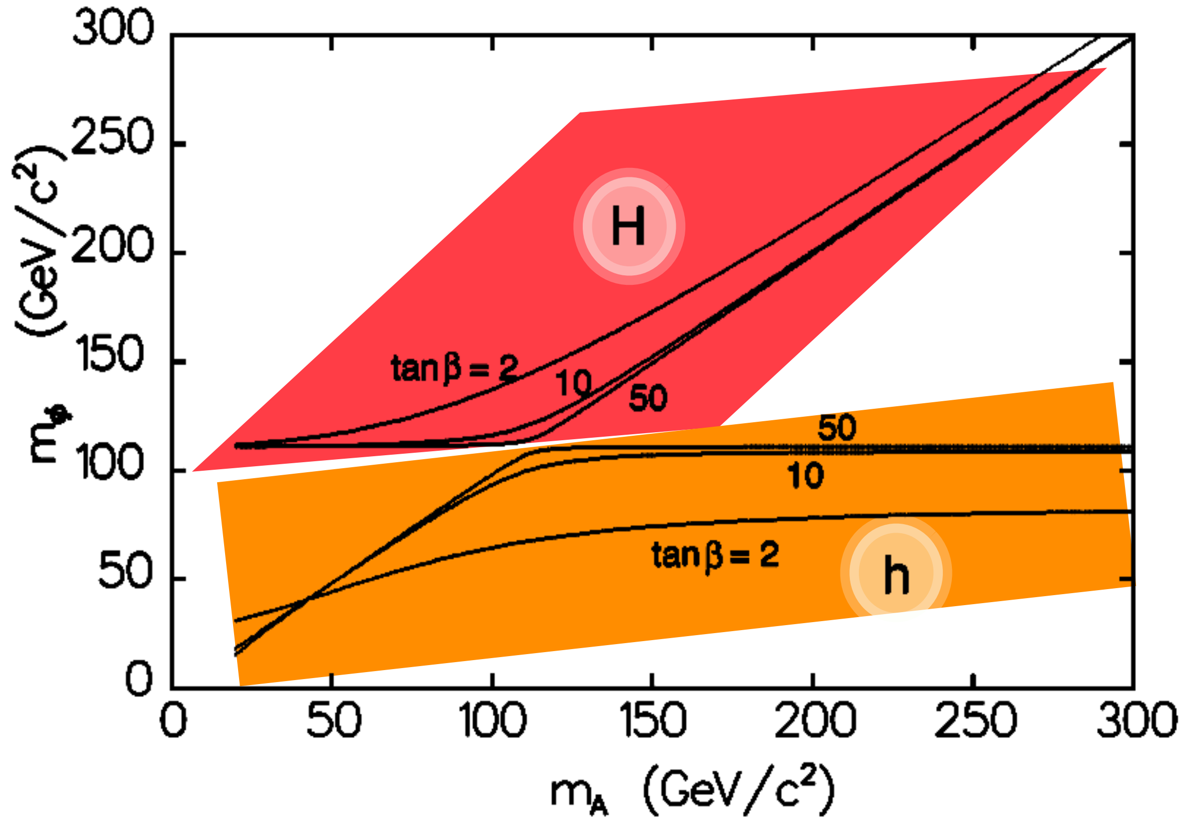




SUSY particle		spin
squarks:	$\tilde{q}_1,\ \tilde{q}_2$	0
sleptons:	$\tilde{l}_1,\ \tilde{l}_2$	0
gluinos:	$\tilde{g}_a$	$\frac{1}{2}$
neutralinos:	$\tilde{\chi}^0_1,\ \tilde{\chi}^0_2,\ \tilde{\chi}^0_3,\ \tilde{\chi}^0_4$	$\frac{1}{2}$
charginos:	$\tilde{\chi}^{\pm}_1,\ \tilde{\chi}^{\pm}_2$	$\frac{1}{2}$

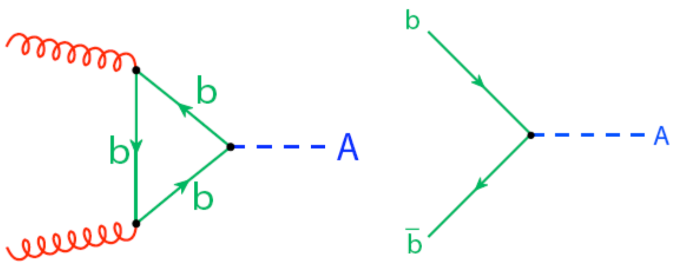
MSSM Higgs sector

- Minimal Supersymmetric extension of the Standard Model
- MSSM is a SUSY model with **2 Higgs doublets**
- 5 Higgs bosons: **h, H, A, H^+ and H^-**
- At tree level, 2 parameters, **m_A and tanβ**, describe the MSSM Higgs sector
- tanβ: **ratio of couplings** to down and up type quarks*
- At large tanβ, 2 neutrals almost **degenerate** in mass, referred as ϕ

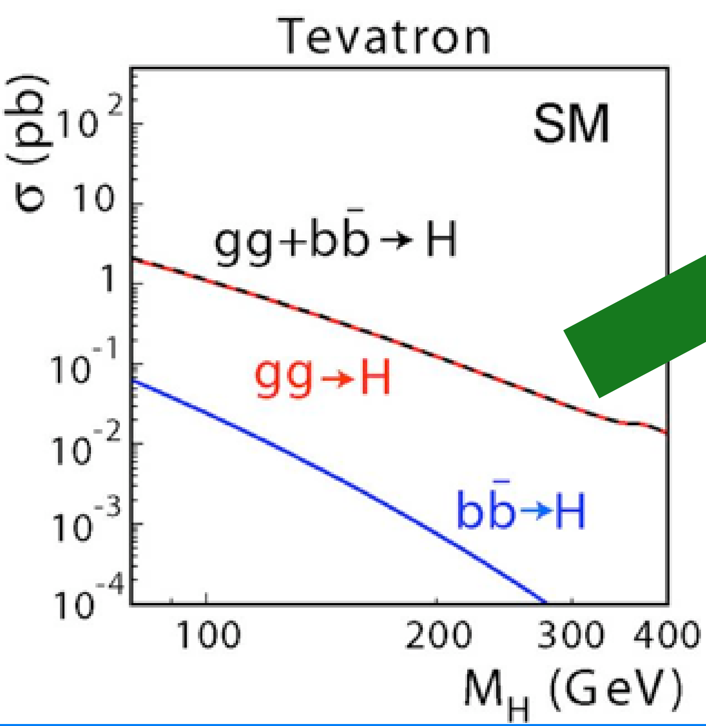


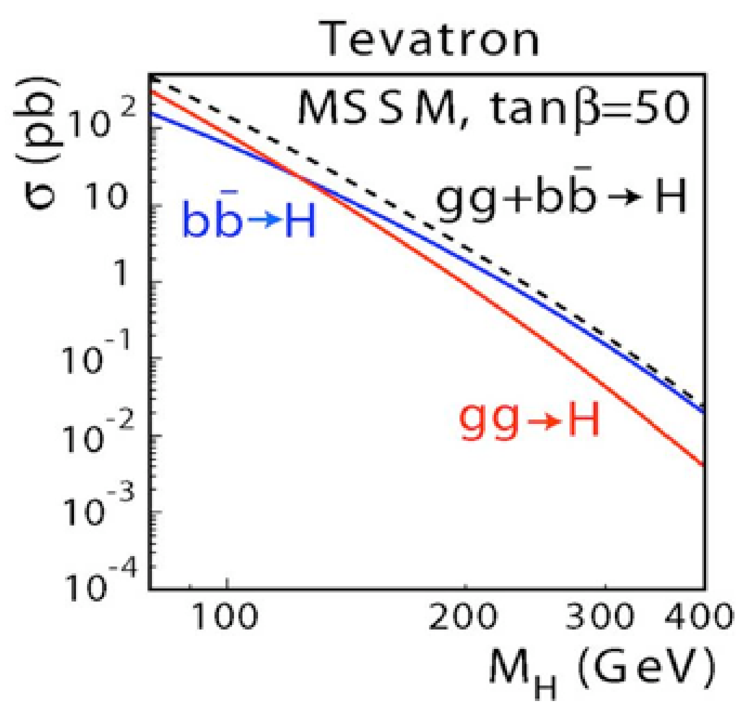
*actually, **tanβ** is the ratio of the VEV of the doublets. The couplings are proportional to the VEV at tree level, before radiative corrections

MSSM at the Tevatron



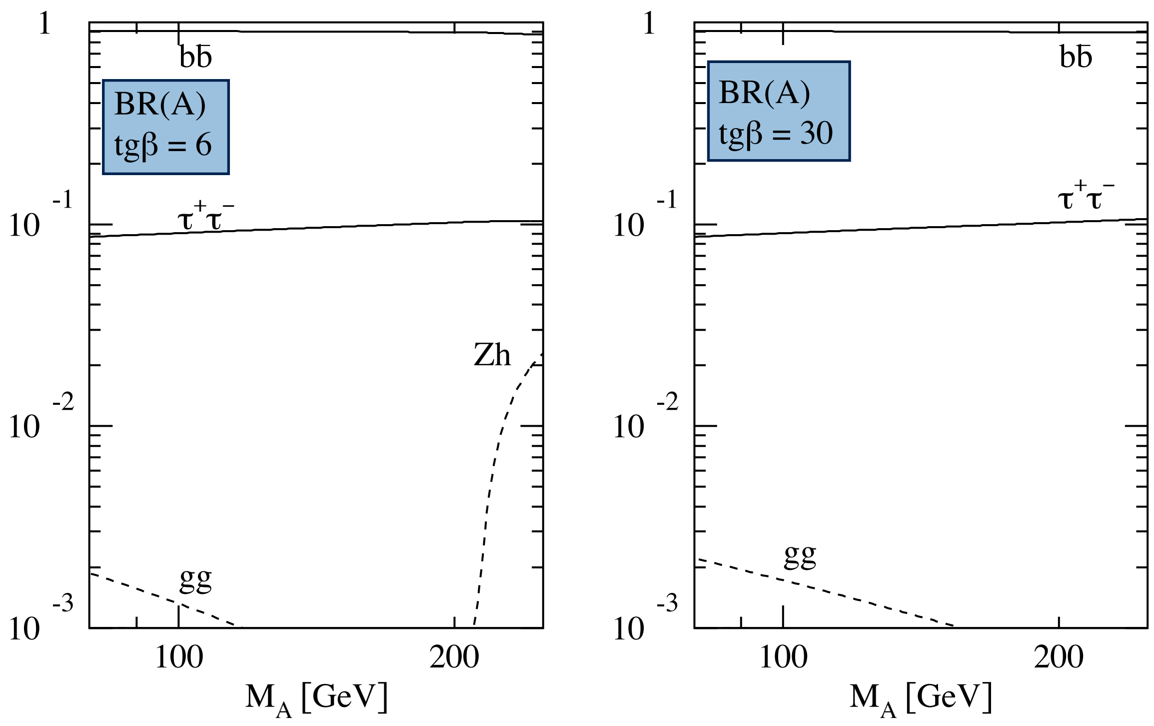
- Two (main) **production** mechanism:
  - gluon fusion (b-quark loop)
  - b-quark annihilation
- Production cross section enhanced by **~tan²β** with respect to SM Higgs





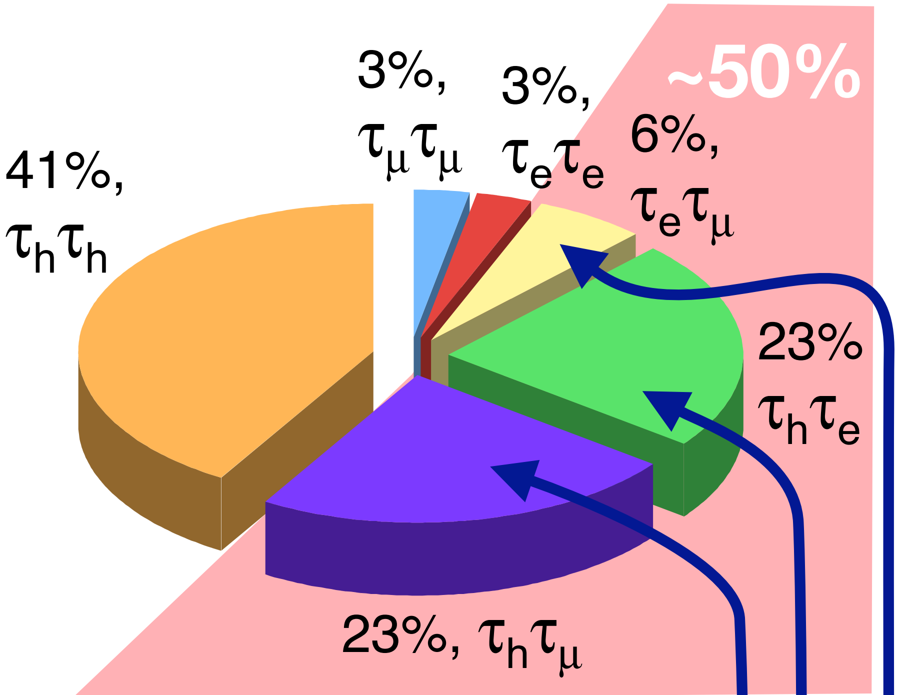
MSSM Higgs decay modes

- Branching ratio neutral Higgs:
  ~ **90% b-quark pairs**
  ~ **10% tau pairs**



- **tau pair** decay mode:
  - smaller branching fraction
  - smaller and better under control backgrounds
  - two production mechanisms can be probed
- **b-quark** pair decay mode:
  - large difficult background (QCD multijet).
    - gg→**ϕ**→bb is not accessible due to dijet background
    - only one prod mechs: bb→**ϕ**→bbb(b)

$\phi \to \tau\tau$ decay channel



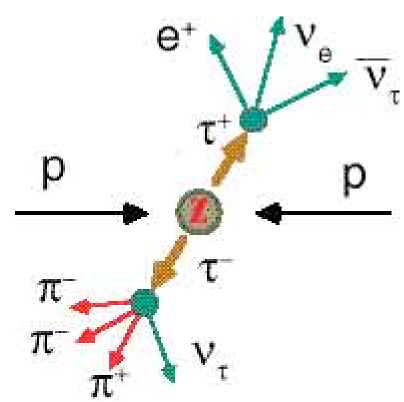
This search is performed with three decay modes:

$\tau_\mu + \tau_h$

$\tau_e + \tau_h$

$\tau_e + \tau_\mu$

- Rich **decay spectrum** of :
  - Leptonic: $\tau \to \upsilon_\tau \upsilon_\ell \ell$, with ℓ being an electron or a muon (35%)
  - Hadronic: $\tau \to \upsilon_\tau X_h$, with X_h being a set of hadrons (65%).
- **Naming**:
  - leptonic tau: τ_e or τ_μ
  - (hadronic) tau: τ_h



- Tau properties:
  - m = **1.7 GeV**
  - mean life = **87 μm**

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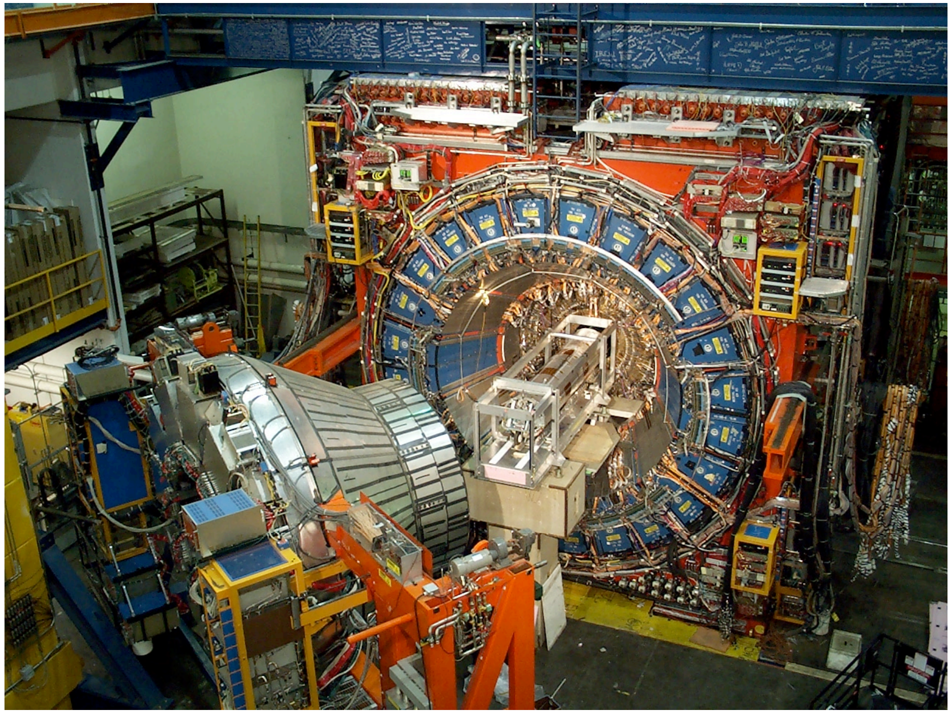
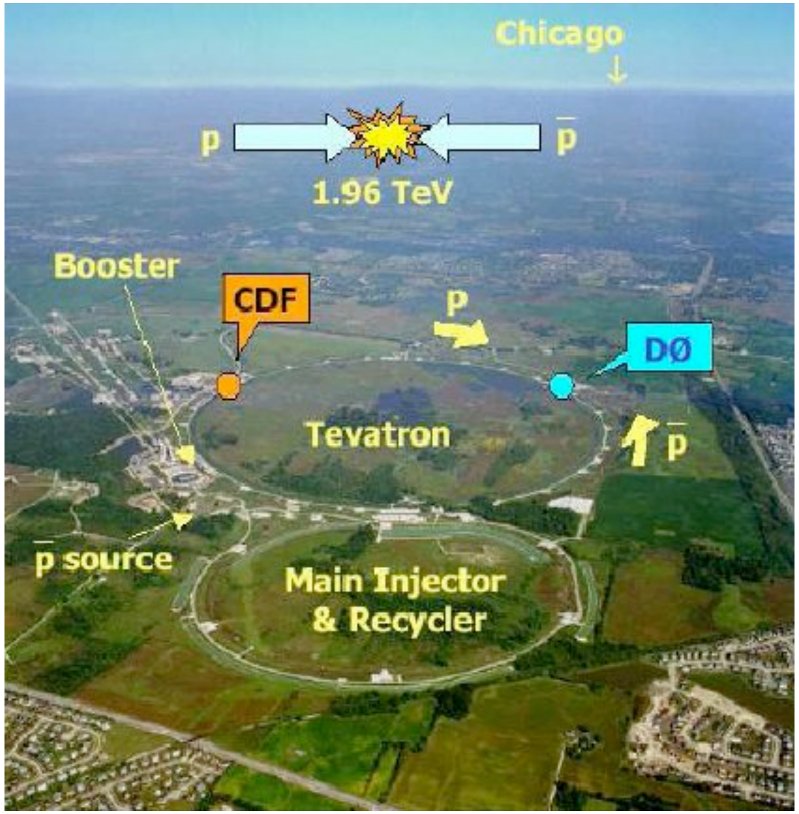
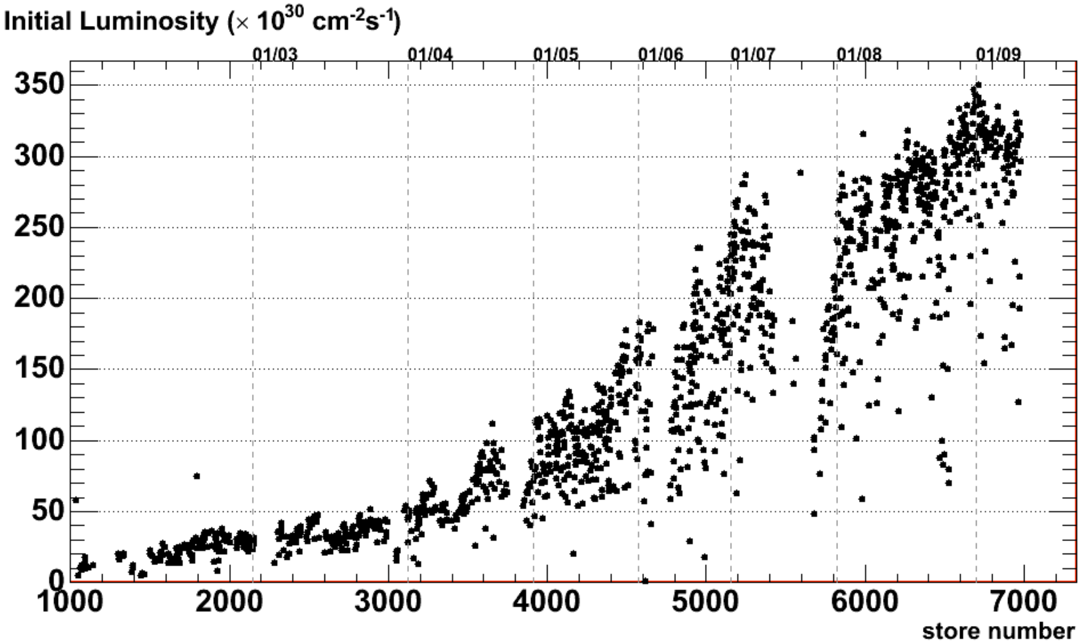


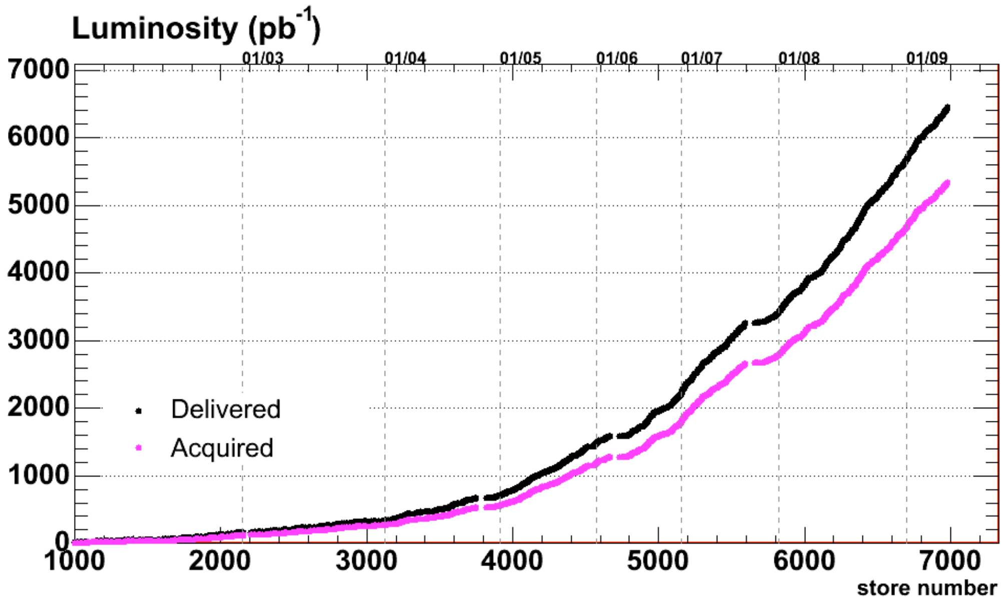
The Tevatron

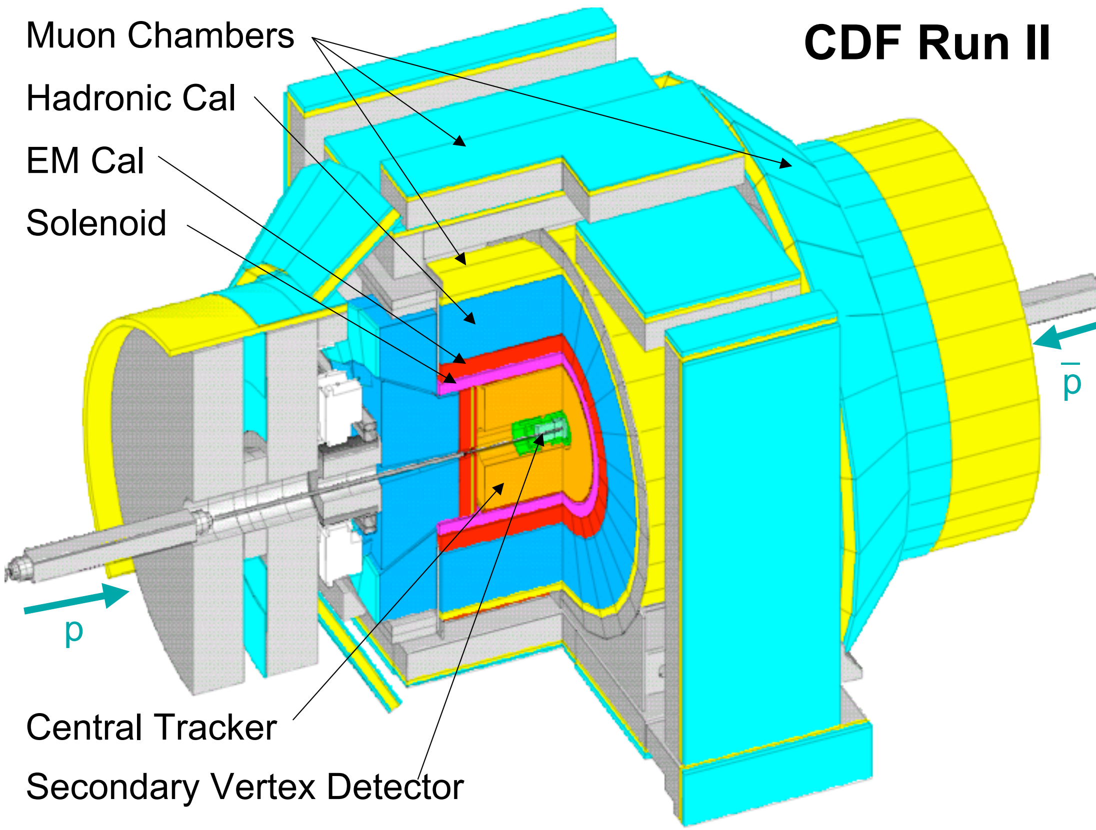
- $p\bar{p}$ collisions at $s^{1/2}$ = **1.96 TeV**
- 36×36 bunches, **396 ns** crossing period.
- Initial instantaneous luminosity record: **>3.50×10^{32} cm^{-2}s^{-1}**.
- Delivered luminosity > **3.5 fb^{-1}** since the beginning of Run II





CDF

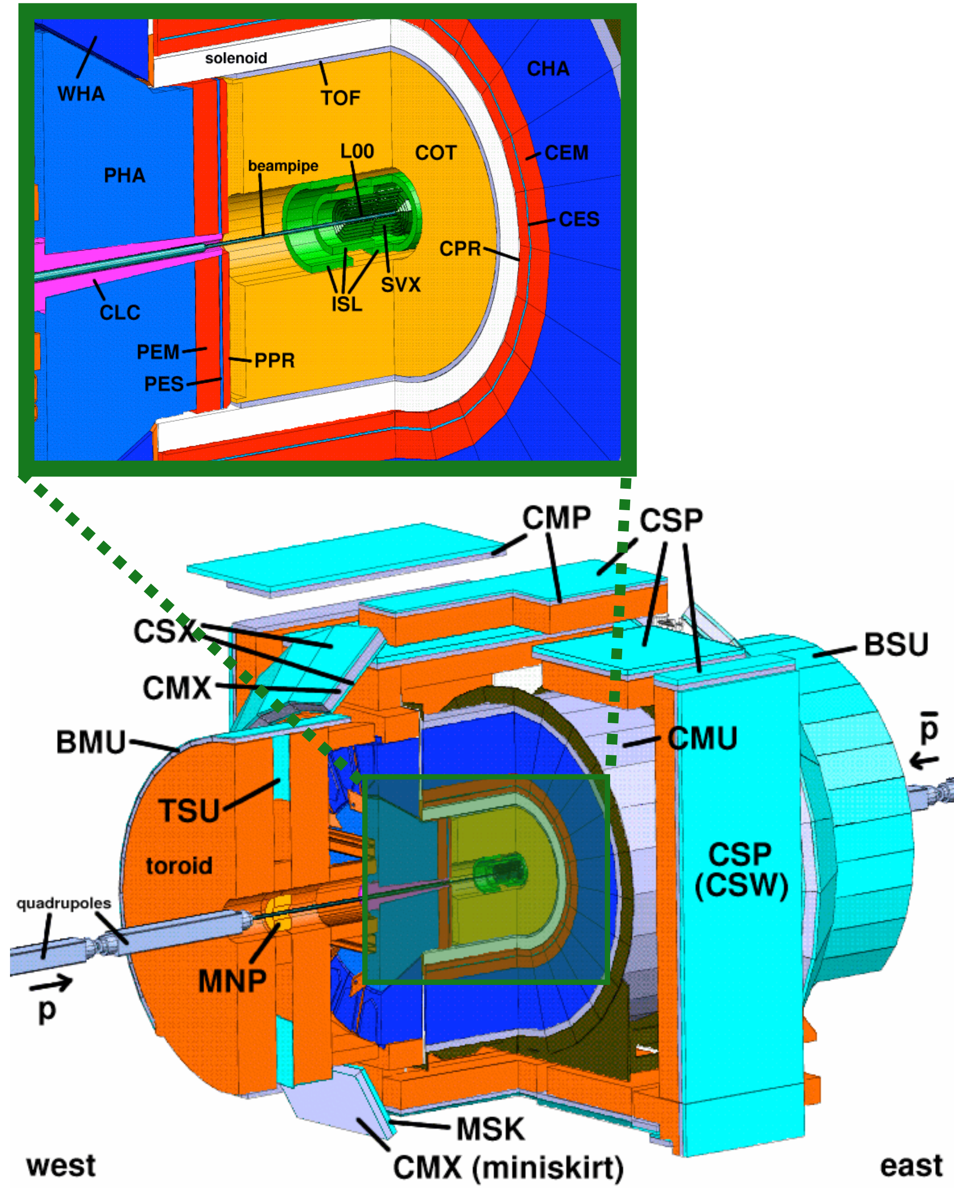




- Over **5 fb^{-1}** of data on tape
- 85% data taking efficiency
- Results shown here: **~1.8 fb^{-1}**

CDF systems

- **Tracking**
  - silicon (not used for this analysis)
  - drift chamber: $|\eta|<1$, 0.15% GeV^{-1}
  - magnetic field 1.4 T
- **Calorimeter**
  - spans $|\eta|<2.4$, $\Delta\eta\simeq0.1$, $\Delta\phi=15$ degrees
  - EM: $13\%/E_T^{1/2}$, HAD: $50\%/E_T^{1/2}$
  - Multiwire-strip chamber at 6X
- **Muon spectrometer**
  - CMU+CMP, $|\eta|<0.7$
  - CMX, $0.7<|\eta|<1.0$



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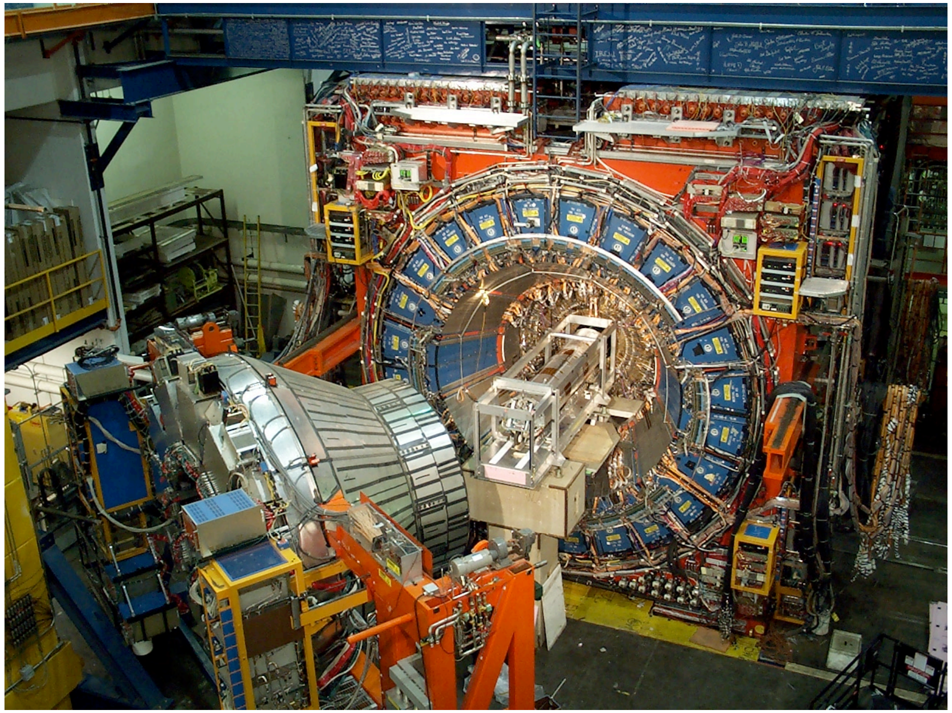


Search strategy

- Look for **inclusive production** of $\phi \rightarrow \tau\tau$:
- Select candidate events compatible with the chosen ditau signatures:
  - $\tau_e + \tau_h$
  - $\tau_\mu + \tau_h$
  - $\tau_e + \tau_\mu$
- **No additional** particles required/vetoed
- Build discriminant variable for signal/background separation:
  - visible mass, $\mathbf{m_{vis}}$
- Perform a **profile likelihood fit** to extract signal and set exclusion limits
- Scan different masses and translate **limits to MSSM** scenarios

Data samples and trigger

final state

$\tau_\ell + \tau_h$

Lepton + track

1 lepton, E_T> 8 GeV
+
1 isolated track, p_T > 5 GeV

$\tau_e + \tau_\mu$

Susy dilepton

1 lepton > 4 GeV
+
1 lepton > 4, 8 GeV

trigger studies / fake rate

High Pt leptons

1 lepton > 18 GeV

Jets

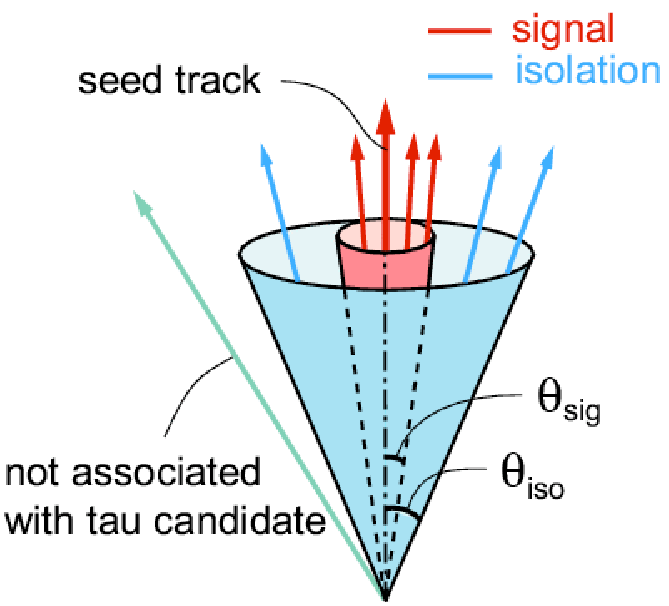
1 jet > 20, 50, 70, 100 GeV

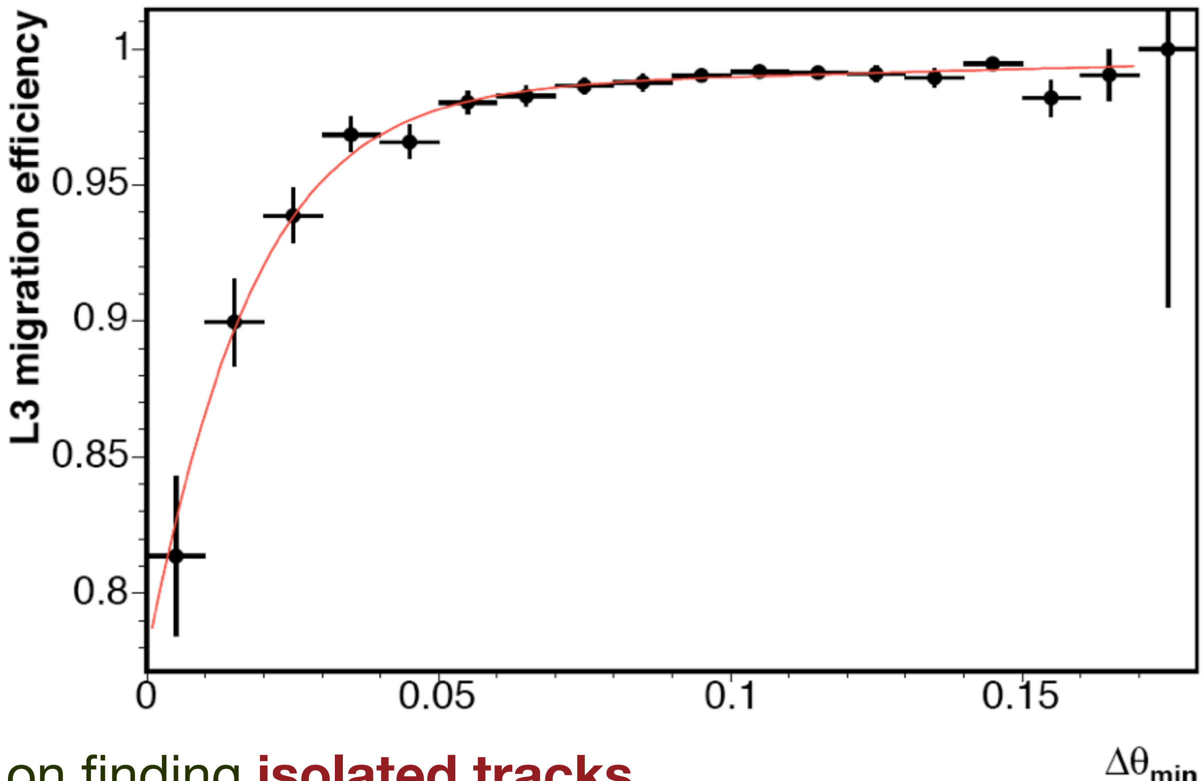
tau energy scale

TauMet

1 tau > 10 GeV
+
met > 25 GeV

Sources of trigger inefficiency





- Hadronic tau trigger is based on finding **isolated tracks**
- **Track finding** (p_T>5GeV) is very efficient at trigger level
- **Isolation** requirements are difficult to model
  - Environment dependent
  - Trigger track quality impacts the efficiency

Lepton+track trigger paths

Trigger Path Family	Trigger Paths involved
"Electron plus track"	TAU_ELECTRON8_TRACK5_ISO
"CMUP plus track"	TAU_CMUP8_TRACK5_ISO, tag 1 to 9 TAU_CMUP8_TRACK5_ISO_L2_LOOSE_DPS TAU_CMUP8_TRACK5_ISO_L2_LOOSE_LUMI_240 TAU_CMUP8_TRACK5_ISO_L2_LOOSE_LUMI_260
"CMX plus track"	TAU_CMX8_TRACK5_ISO TAU_CMX8_TRACK5_ISO_LUMI_200 TAU_CMX8_TRACK5_ISO_L2_LOOSE_DPS TAU_CMX8_TRACK5_ISO_L2_LOOSE_LUMI_200

- One trigger path for **electrons**, but a few changes in time:
  - **L2 cluster** match requirement was included
  - **L3 isolation** requirement changed
- Two flavors of **muons** (different detectors), also underwent changes:
  - **L2 XFT** track match requirement added
  - **L3 isolation** requirement changed

Requirements at 2nd and 3rd trigger level

- The **requirements** for the track leg of the trigger differ for the various paths and versions

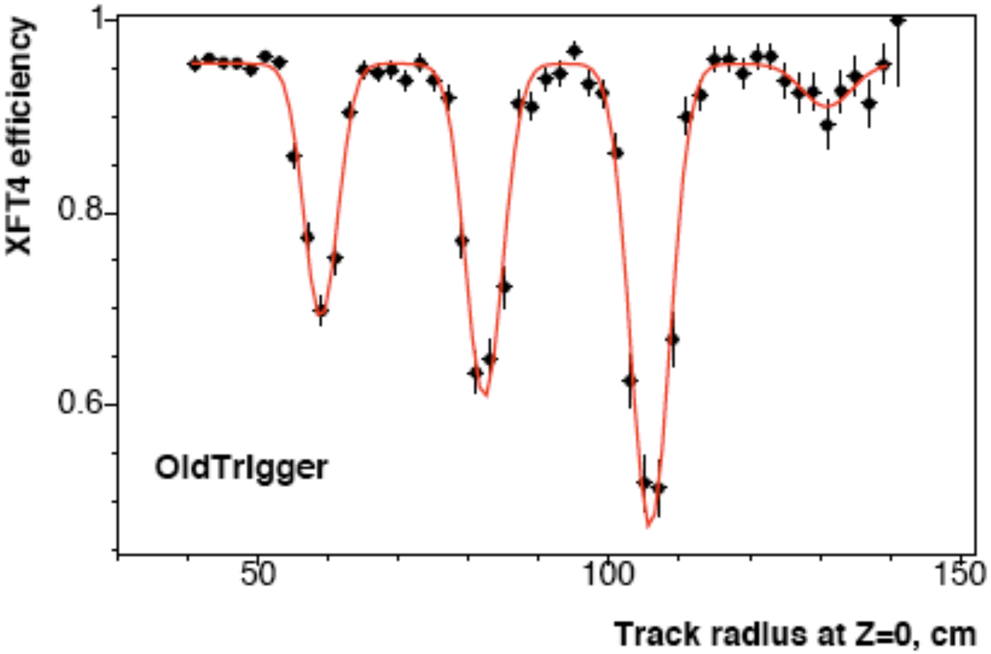
- **L2 XFT** requirement:
    - track pT > 5 GeV
    - 3 or 4 matches

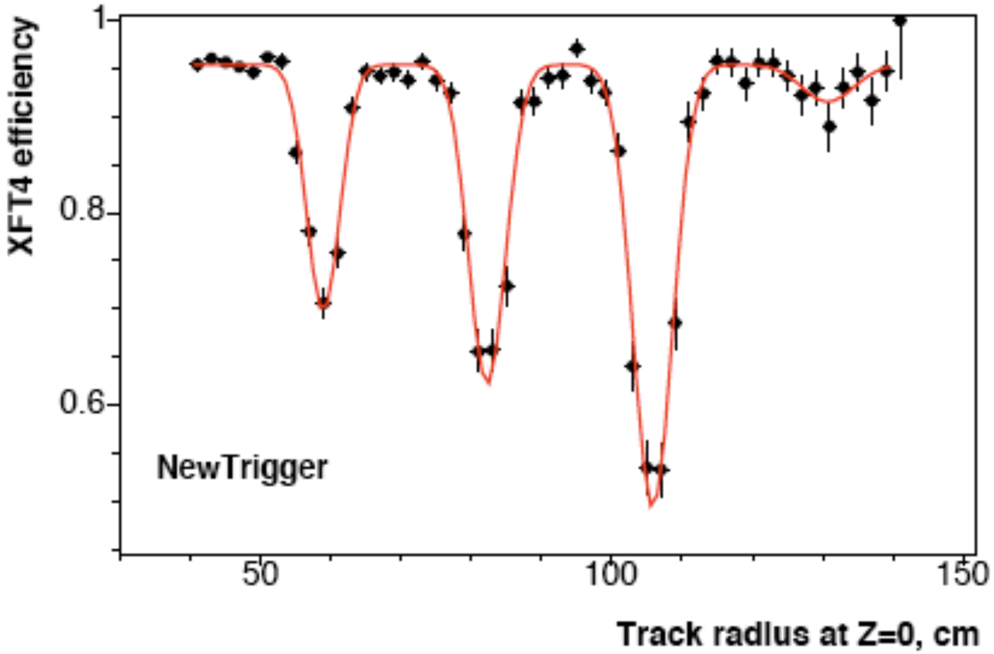
L2 cluster requirements
$E_T > 4GeV$
Number of towers ≤ 5
pass $= 2$

L3 track requirements
$p_T > 5GeV$
$\|\eta\| < 1.5$
isolation

	"old trigger"	"new trigger"
L3 isolation annulus	$0.175 < \Delta R < 0.524$	$10degrees < Angle < 30degrees$
track cuts	$\|\Delta Z\| < 15\ cm$ $p_T > 1.5\ GeV$	$\|\Delta Z\| < 5\ cm$ $p_T > 1.5\ GeV$

L2 tracking efficiency: XFT matches

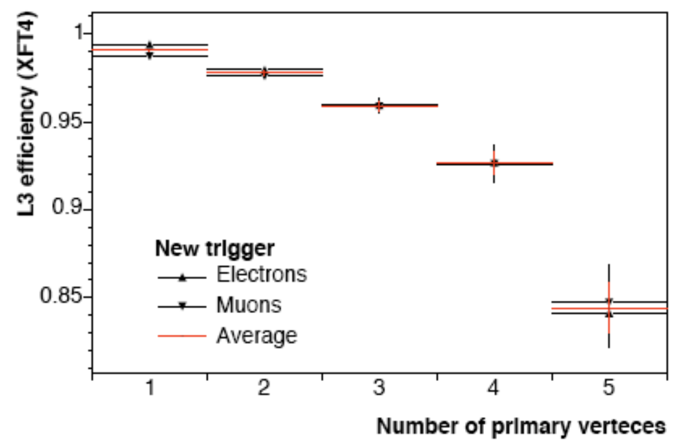


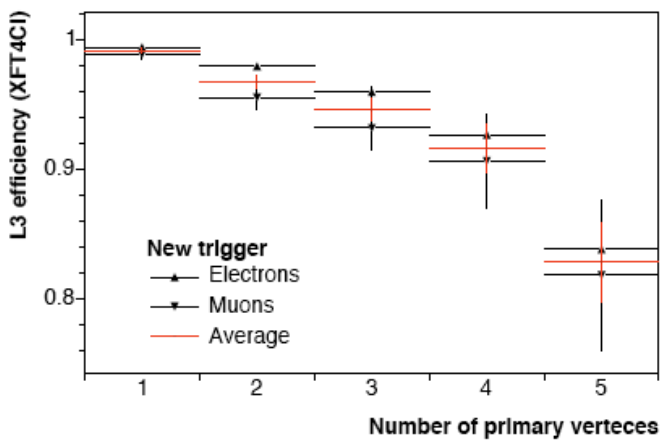


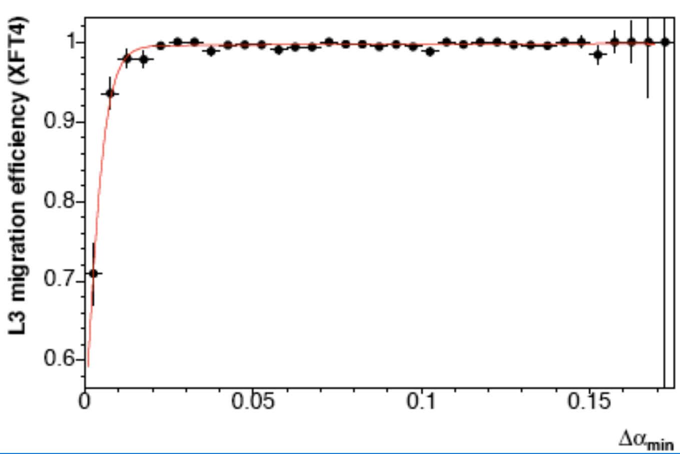
- We found the tracking trigger efficiency depends on several **geometrical factors** like the radius at which the track crosses the central plane of the detector or the path of the track in the tracking volume

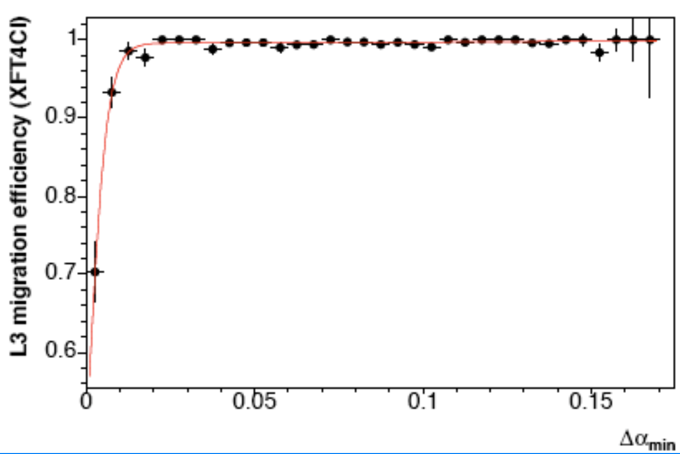
L3 isolation: a nightmare

- Isolation introduces dependencies on **event activity**, it is **luminosity** dependent and requires to account for differences between **online and offline** object reconstruction









Trigger paths & integrated luminosity

trigger path name	0d	0h	0i	0j	total
TAU_ELECTRON8_TRACK5_ISO	317683	392143	857877	241040	1808743
TAU_CMUP8_TRACK5_ISO, tag 1 to 9	317683	392143	857082	44882	1611790
TAU_CMUP8_TRACK5_ISO_L2_LOOSE_DPS				33910	33910
TAU_CMUP8_TRACK5_ISO_L2_LOOSE_LUMI_240				131990	131990
TAU_CMUP8_TRACK5_ISO_L2_LOOSE_LUMI_260			747	4285	5032
	317683	392143	857829	215067	1782722
TAU_CMX8_TRACK5_ISO	317683	392143	486631		1196457
TAU_CMX8_TRACK5_ISO_LUMI_200			347935	41557	389492
TAU_CMX8_TRACK5_ISO_L2_LOOSE_DPS				31267	31267
TAU_CMX8_TRACK5_ISO_L2_LOOSE_LUMI_200			747	130891	131638
	317683	392143	835313	203715	1748854
EDIL	318138	392143	857809	241062	1809152

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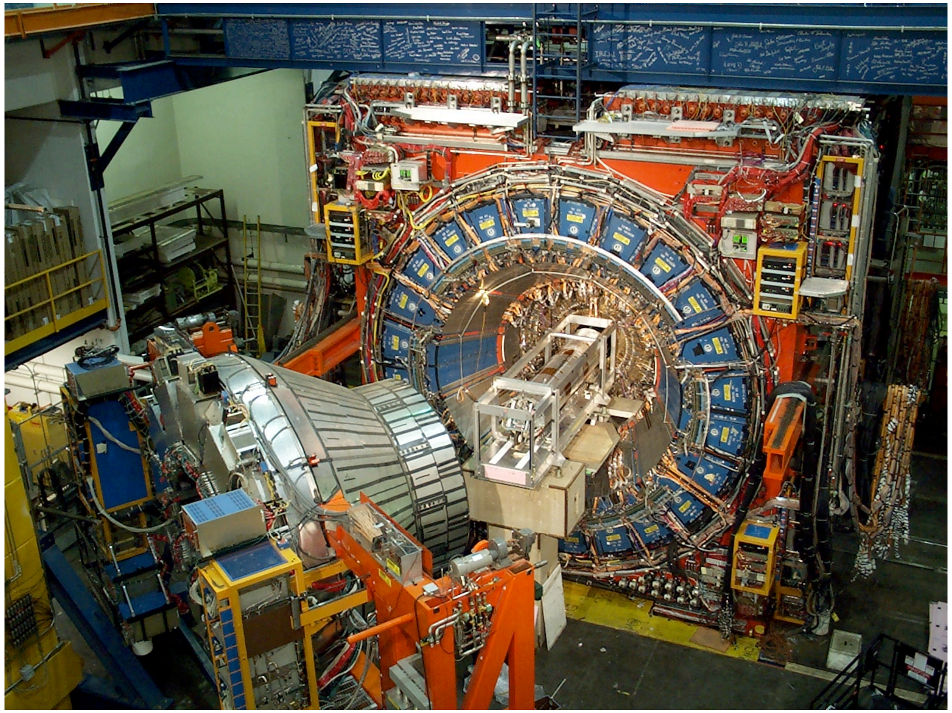
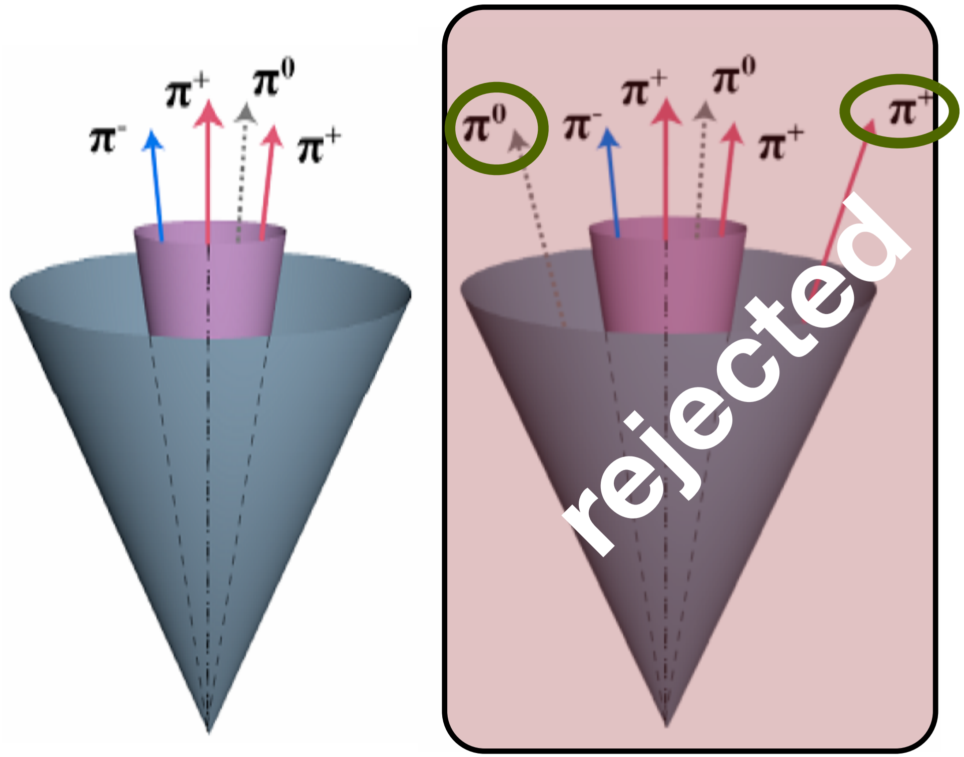
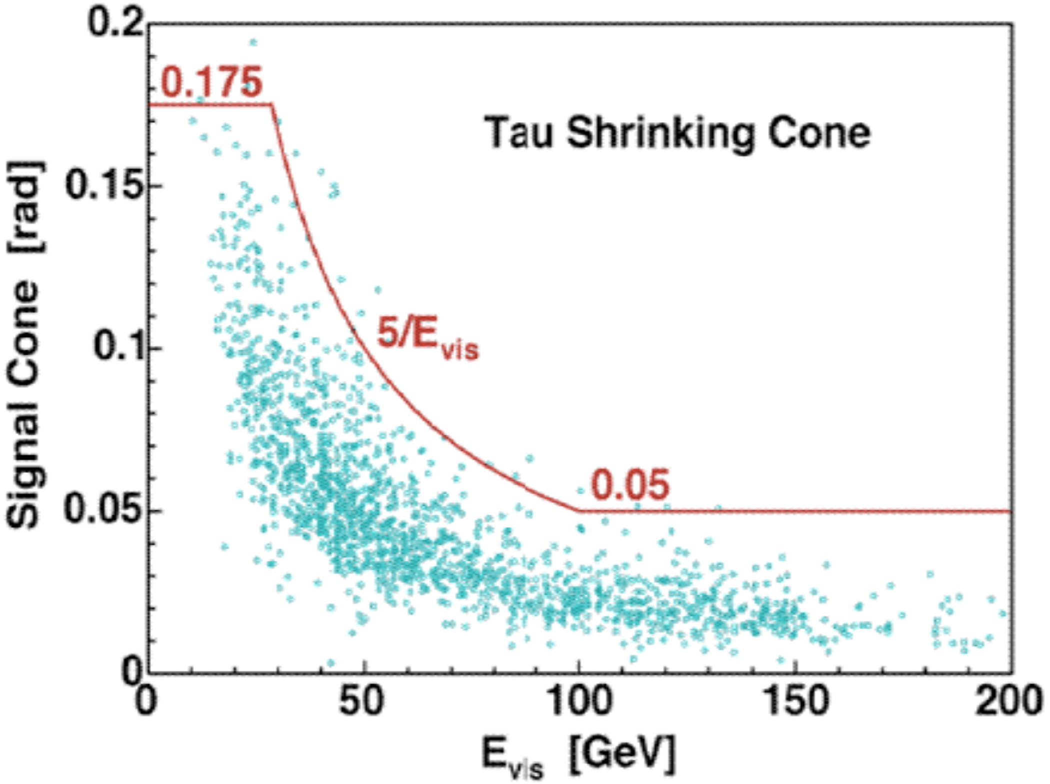


Reconstruction of hadronic taus at CDF

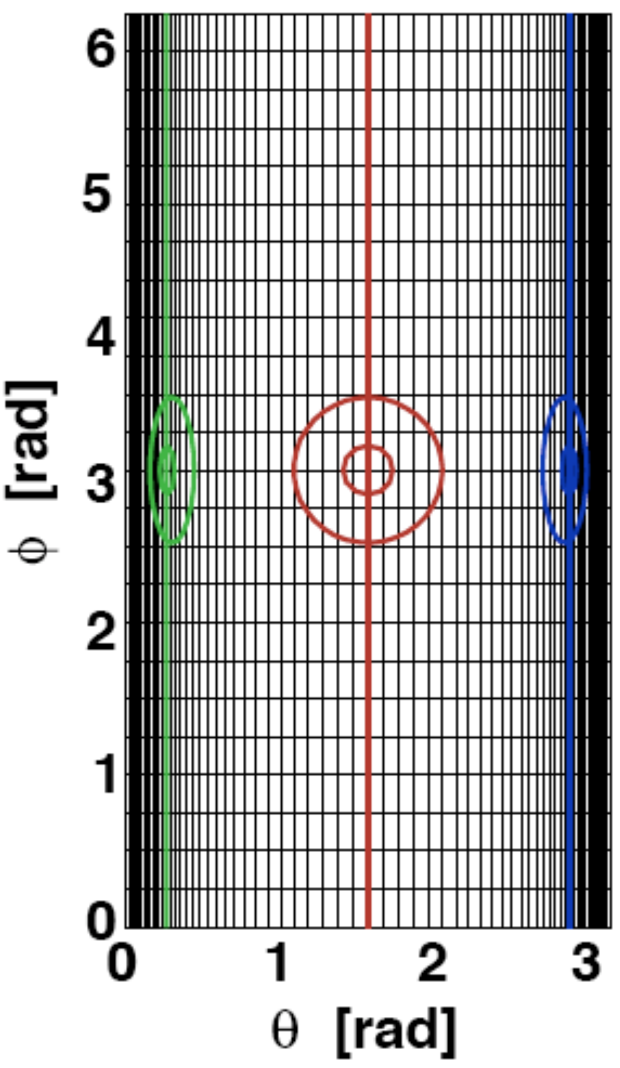
- Match a **high p_T track** and a calorimeter cluster
- Add tracks and neutrals in **shrinking cone**

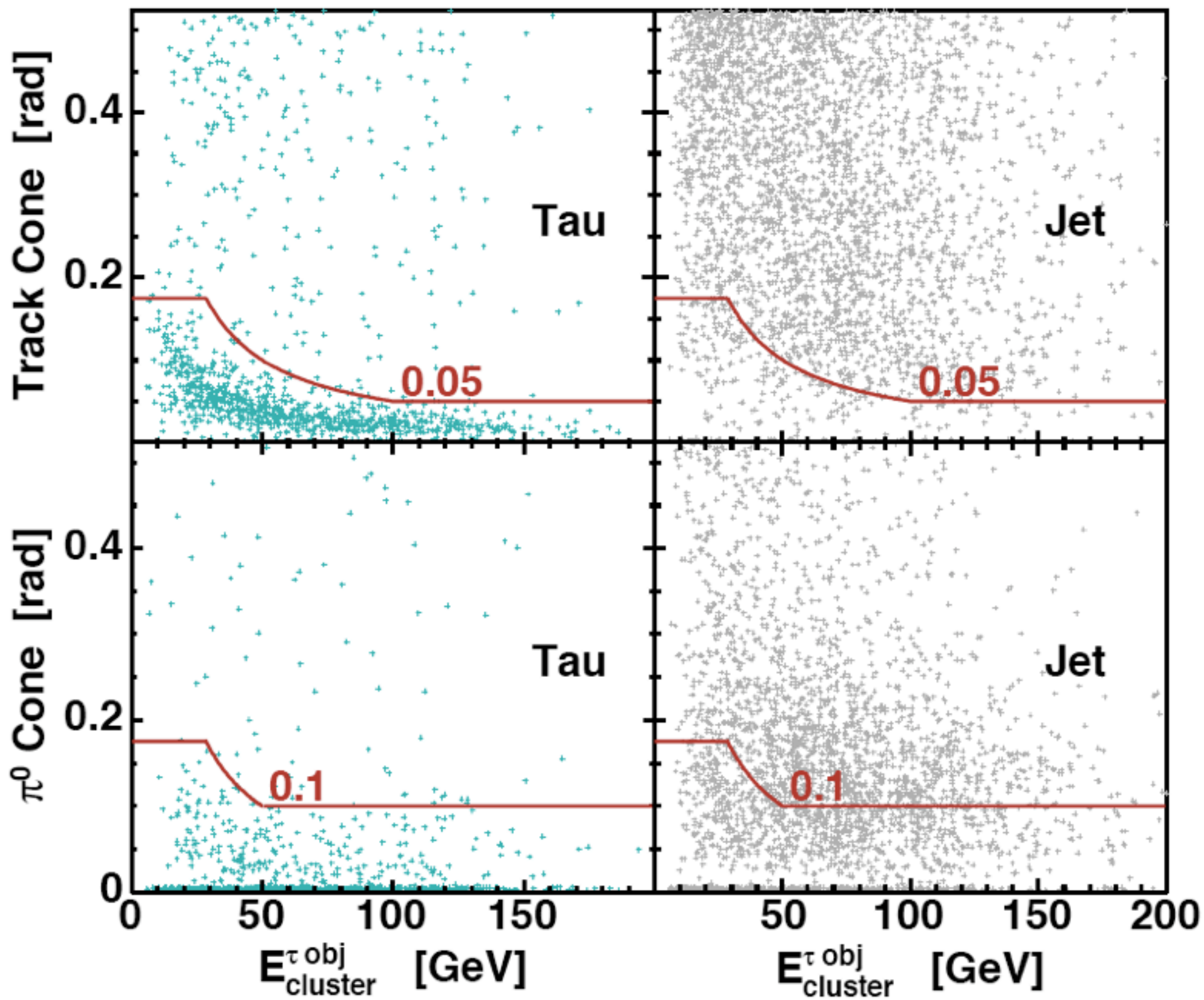




- Veto tau candidates with tracks or neutrals in **isolation annulus**
- The angle of the **signal cone** (10 degrees) shrinks with the calorimeter energy (down to 3 deg for tracks and 6 deg for neutrals)

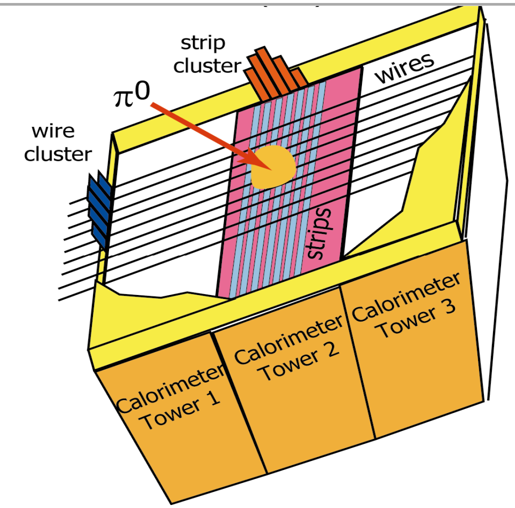
Shrinking cone

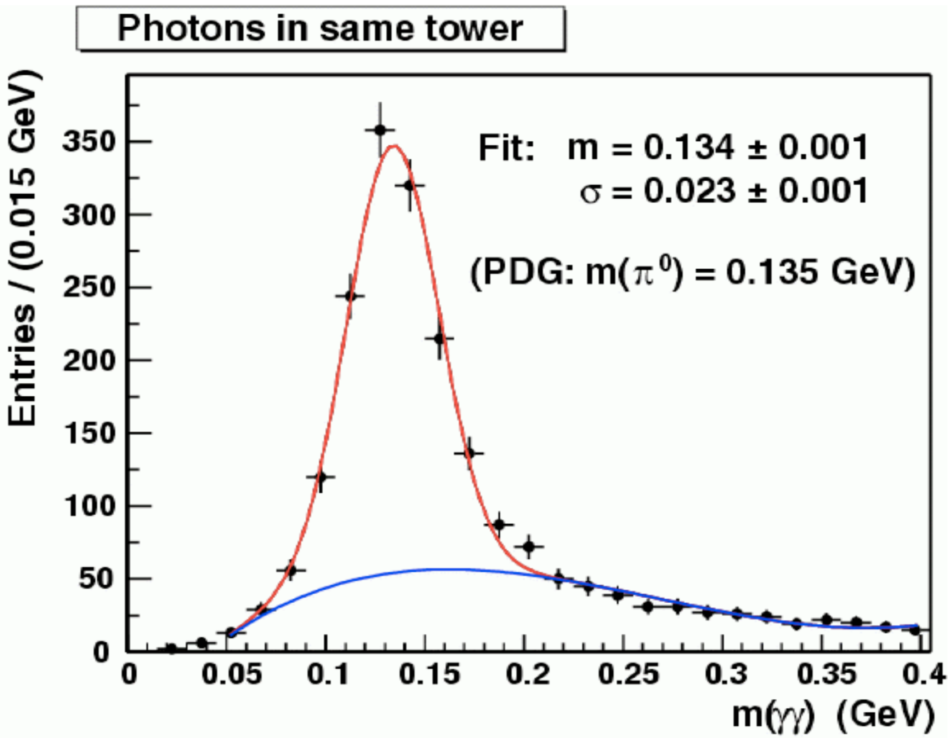




π^0 reconstruction at CDF

- Very **important** capability for good resolution in the visible **tau momentum**
- Based on **ShowerMax** wire-strip matches
- Relevant in analysis like this search





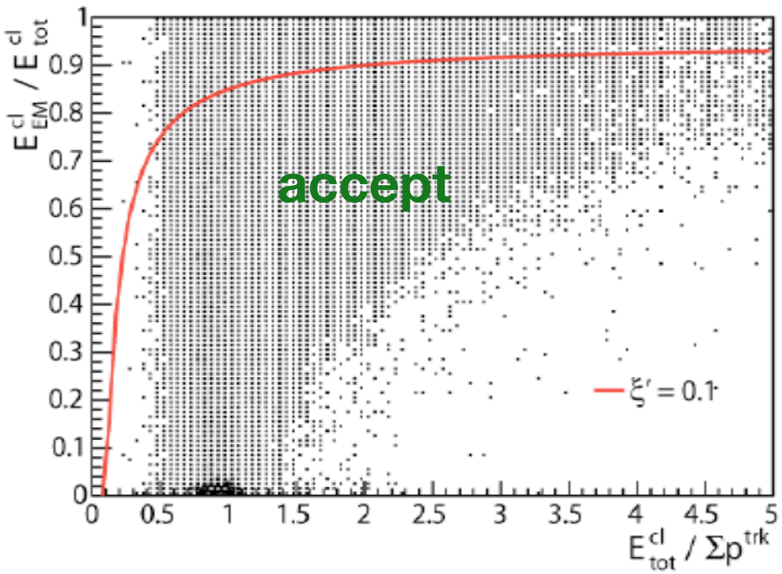
- ShowerMax:
  - at 6X, embedded in the EM calorimeter
  - wires run parallel to beam
    strips run perpendicular to beam
- Clusters are 5x5 wide
- Capable to reconstruct π^0 mass from photons

Hadronic tau identification

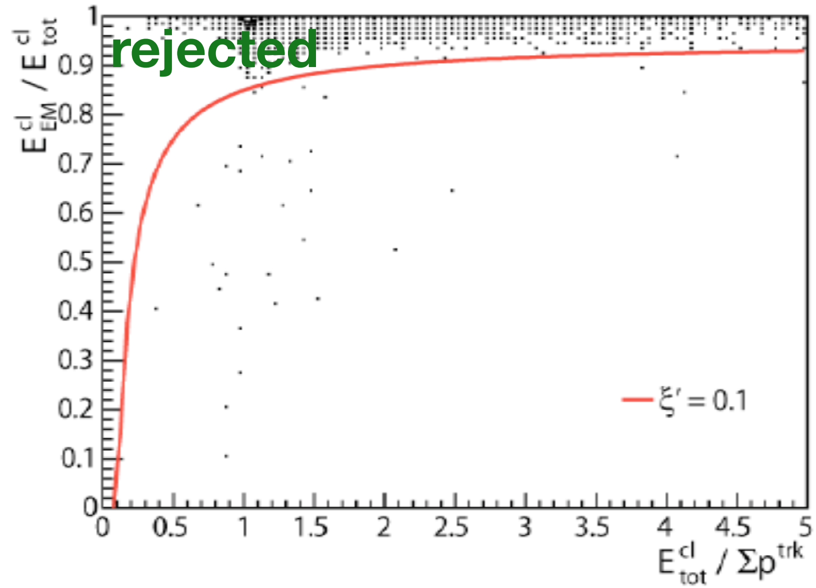
- number of tracks, $N^{trk}=1,3$
- $E_T^{cl} > 9$ GeV
- pT>15 GeV for 1 prong
  pT>20 GeV for 3 prong
- ξ' > 0.1
- track isolation: $\Sigma_{iso} p_T^{trk} < 2$ GeV
- π^0 isolation: $\Sigma_{iso} E_T^{\pi^0} < 1$ GeV
- $m_{had} < 1.8$ GeV for 1 prong
  $m_{had} < 2.2$ GeV for 3 prong

$$\xi' = \frac{E_{tot}}{\sum |\vec{p}|}\left(0.95 - \frac{E_{EM}}{E_{tot}}\right)$$

taus

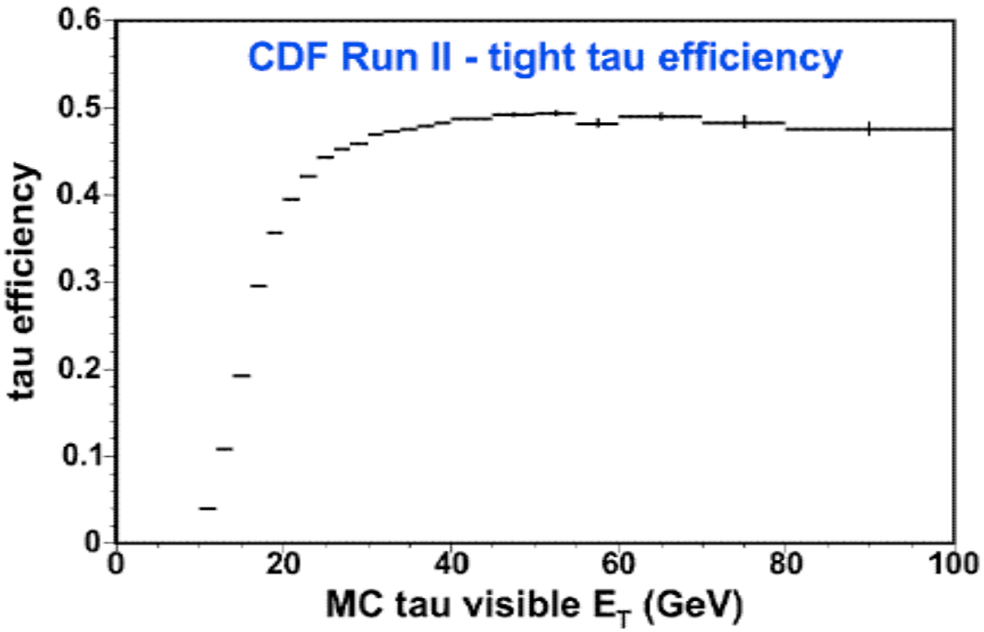


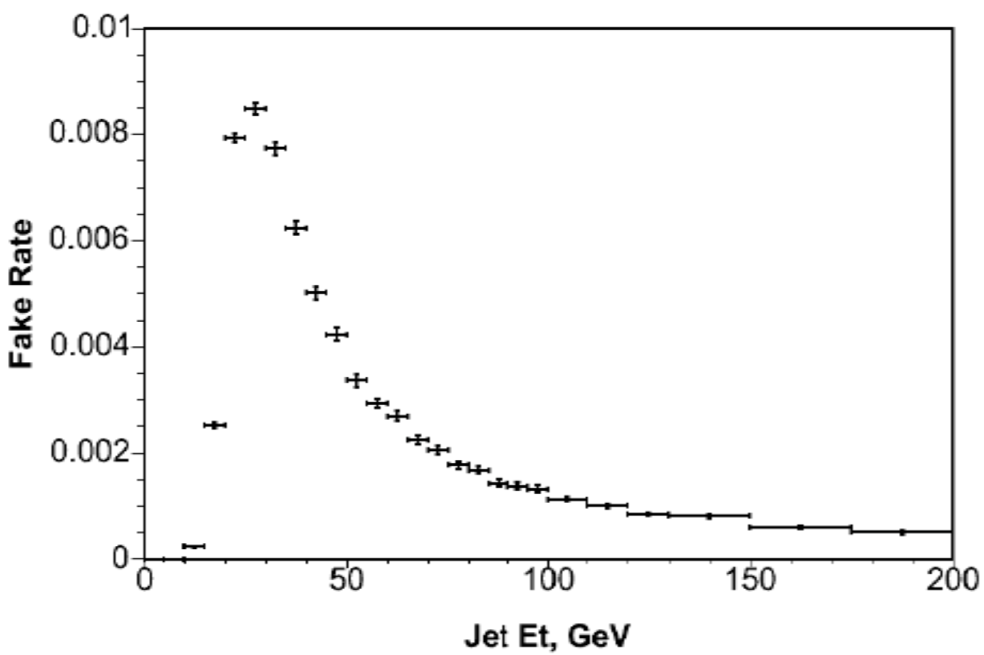
electrons



Tau (mis)identification efficiency

- Efficiency for **MC** taus
- depends heavily on identification requirements, especially **isolation**

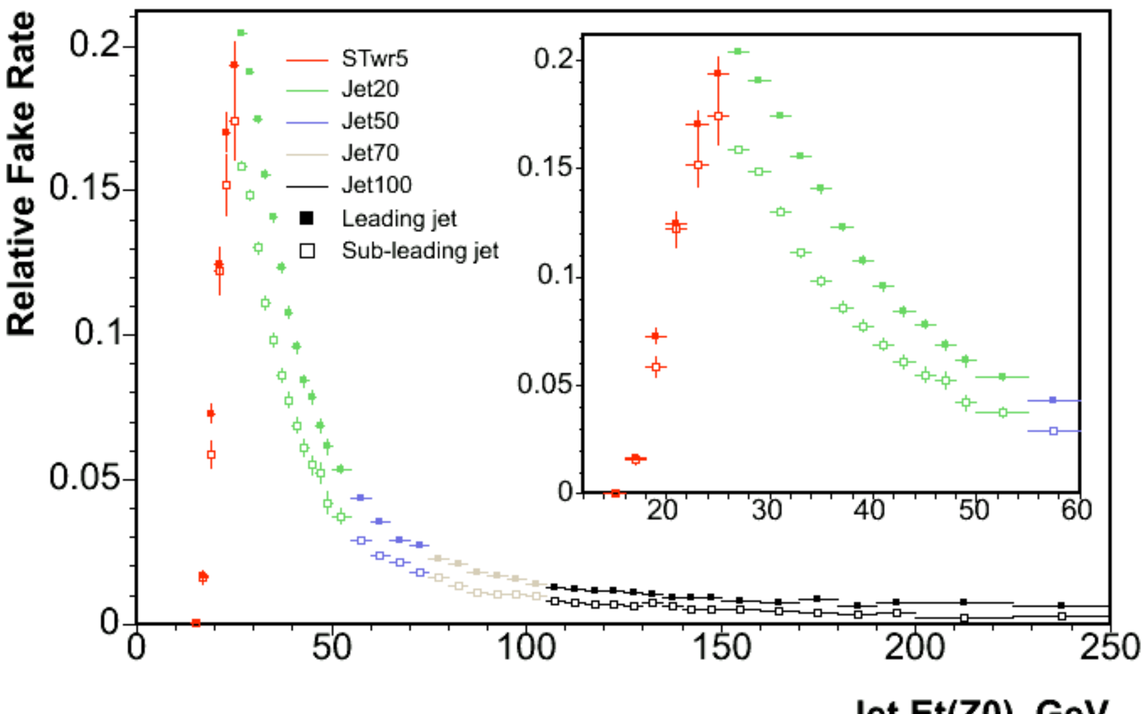




- Calculated from **samples of jets** (very low contamination of real taus)
- **Ratio** of “loose” taus that are identified as “tight”
- Loose: the **loosest allowed** by the trigger in final state

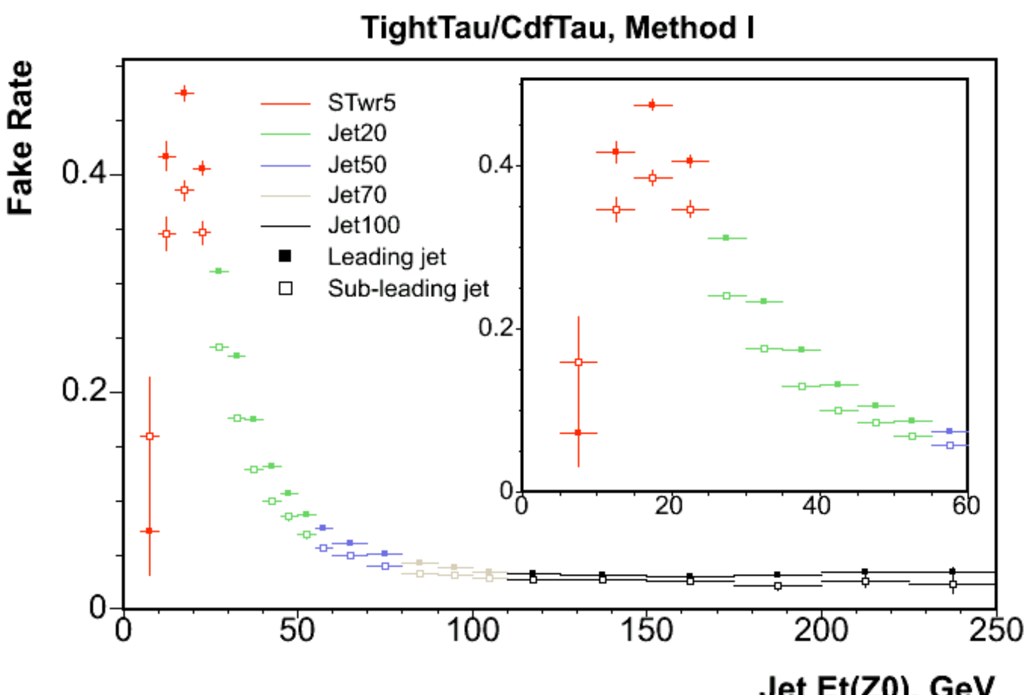
More on jet→τ fake rates, I

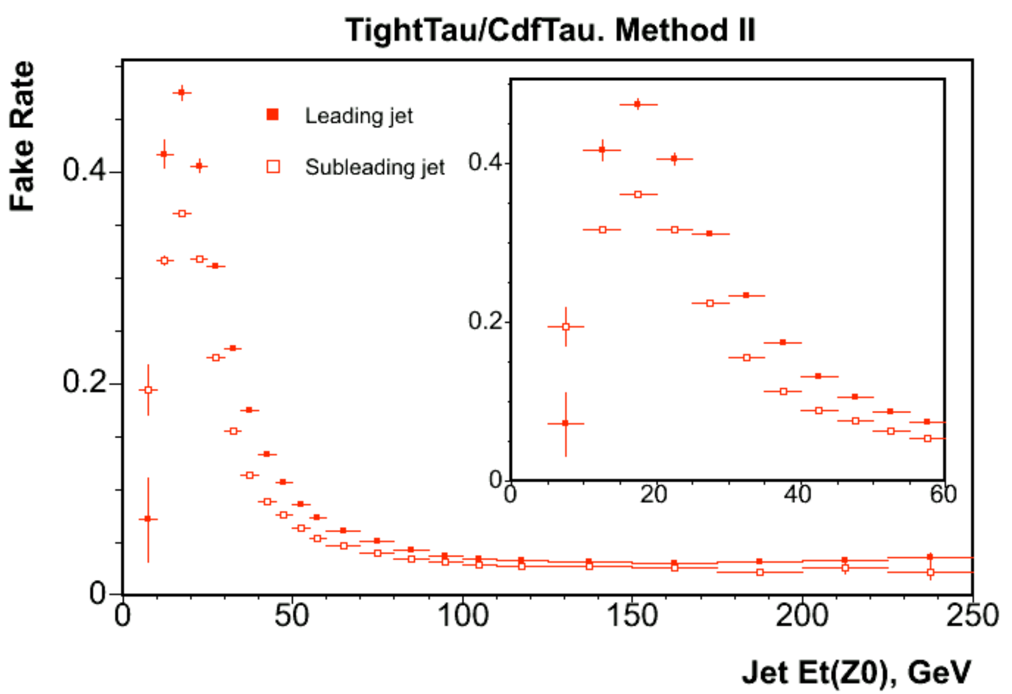
- First attempt: generic **jets**, this makes things tricky
- Second attempt: the **loosest possible object**: isolated track (from trigger requirements)
  - pT > 5 GeV
  - isolation: no tracks with pT>1.5 GeV in 0.175<DR/alpha<0.524 and DZ0<15



More on jet→τ fake rates, II

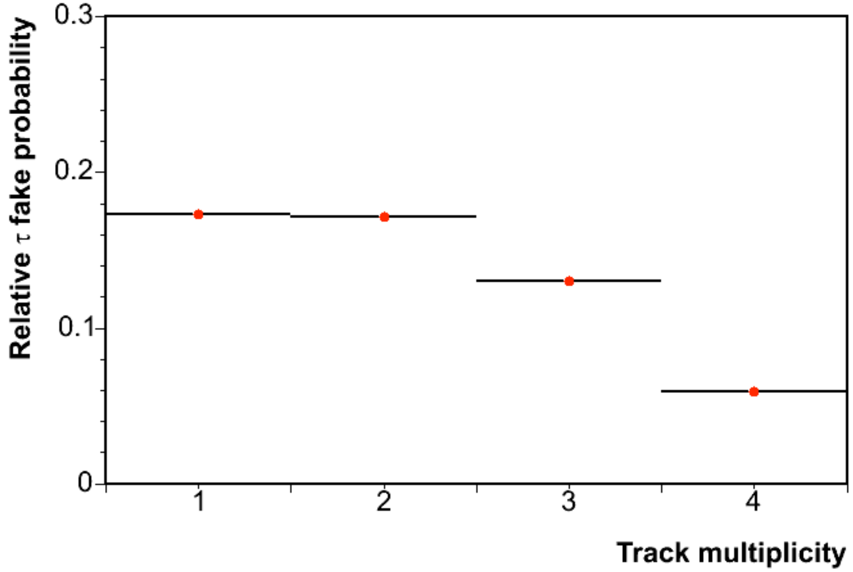
- We can't go too loose nor too far from "**tau**". Final loose object:
  - trigger like isolated track, pT > 6 GeV
  - fiducial
  - matching a "tau" calorimeter cluster
- Jet Samples: **trigger bias**

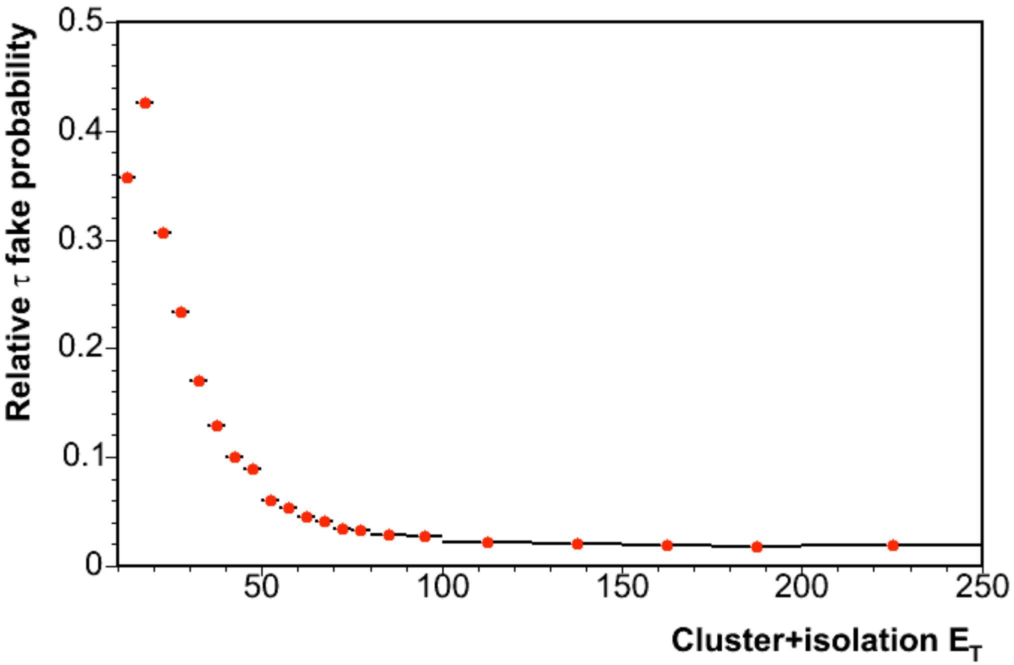


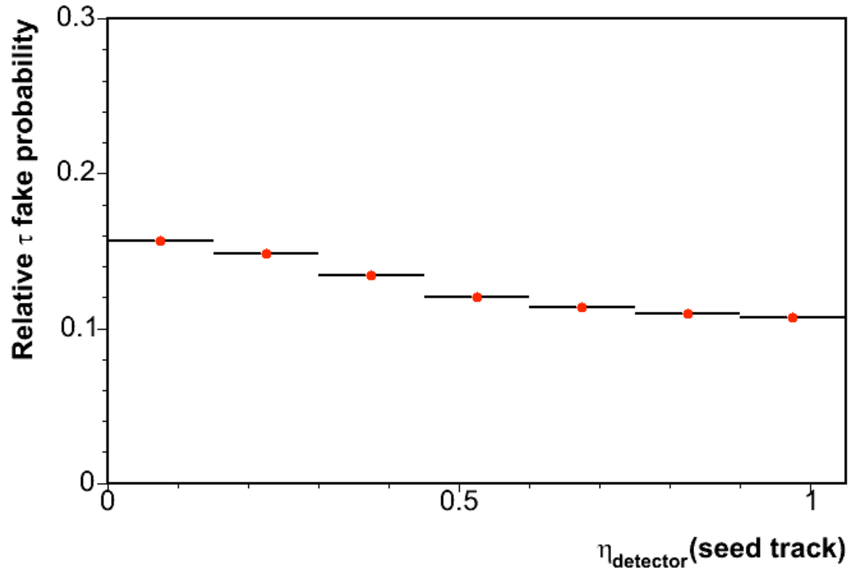


More on jet→τ fake rates, III

- Final fake rates:
  - **two “limit” estimations**: leading and subleading jets (plots show mean)
  - **3D parametrization**: pseudorapidity, track multiplicity and energy in 0.3 cone

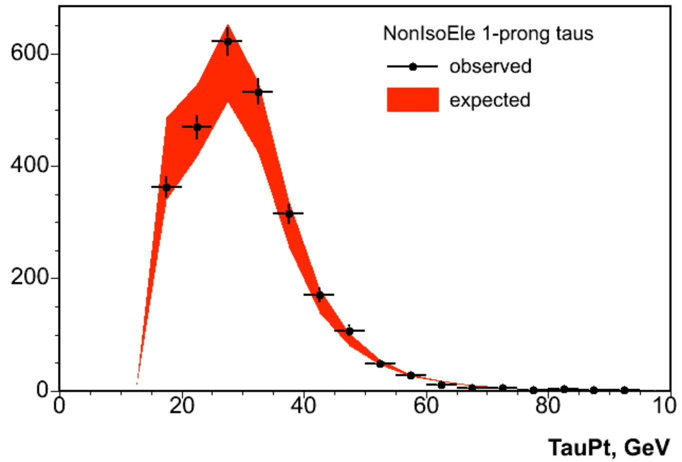


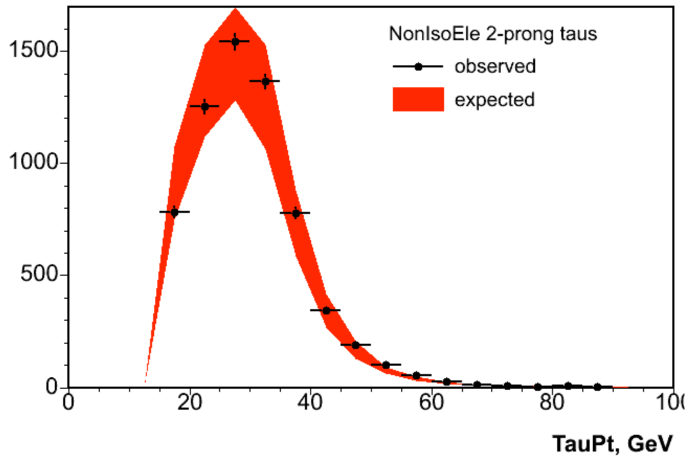


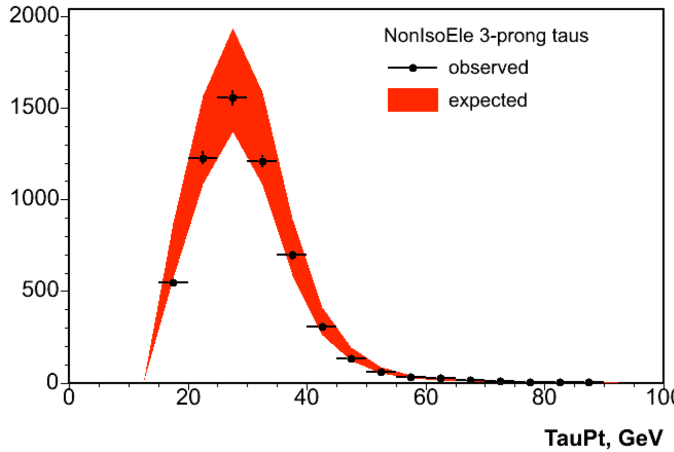


More on jet→τ fake rates, IV

- We identified samples with no real taus to **cross check** our fake estimations
  - W+jets: with a W decaying to a muon or an electron
  - γ+jets: selected with conversion electrons
  - dijet events: non isolated leptons
- Estimation band: from **leading-jet** and **subleading-jet** fake rate estimations

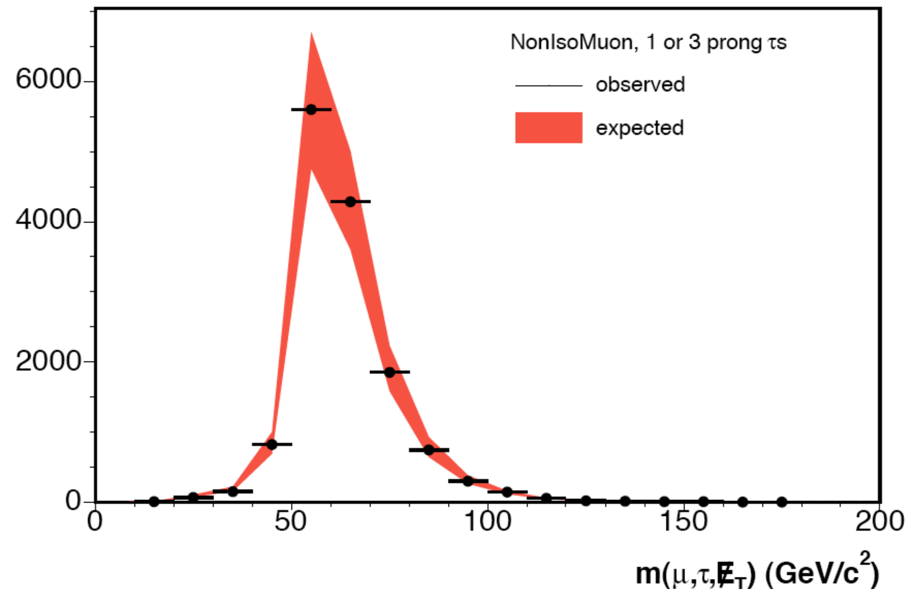


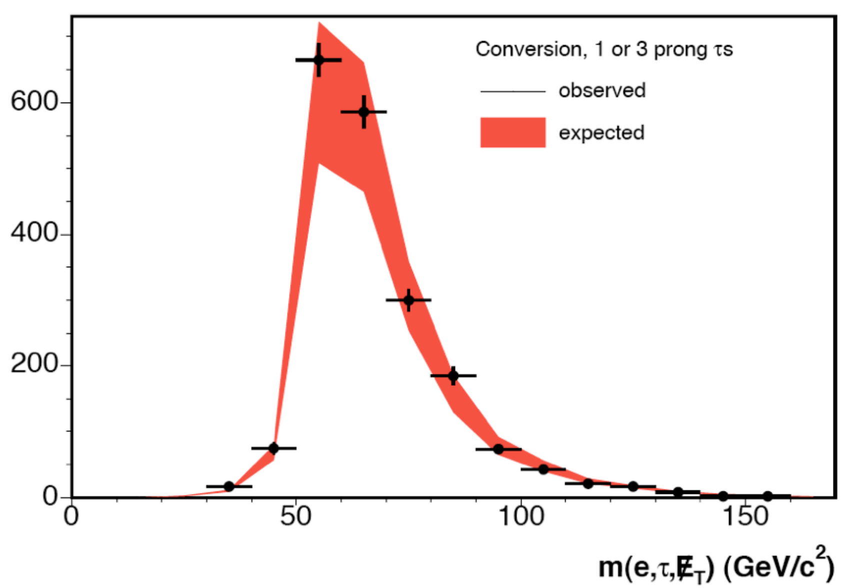


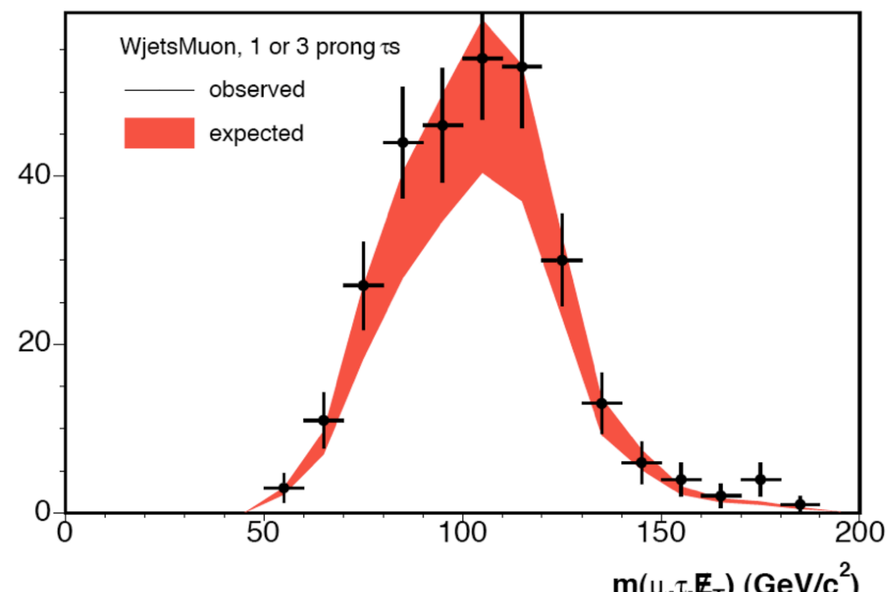


More on jet→τ fake rates, summary

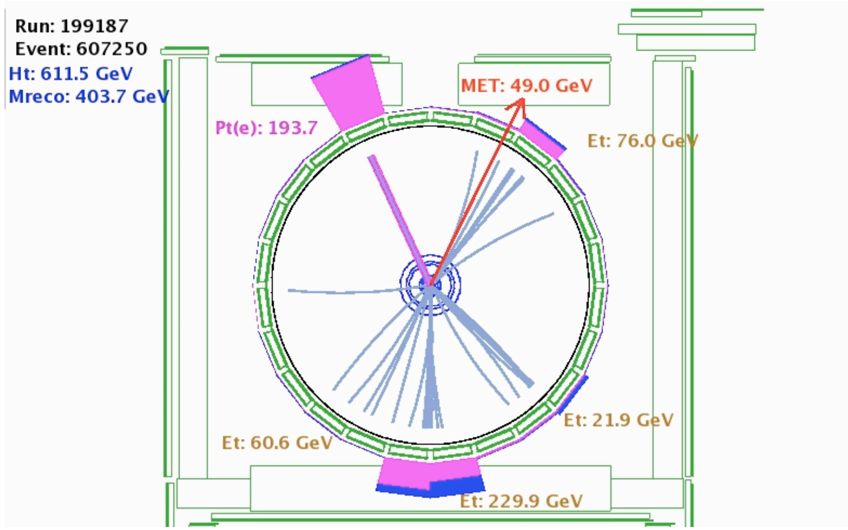
- **Control regions** for QCD background
  - non-isolated leptons: dijet
  - W + jets
  - conversion electrons: γ+ jets
- Bands show assigned **systematic** uncertainty





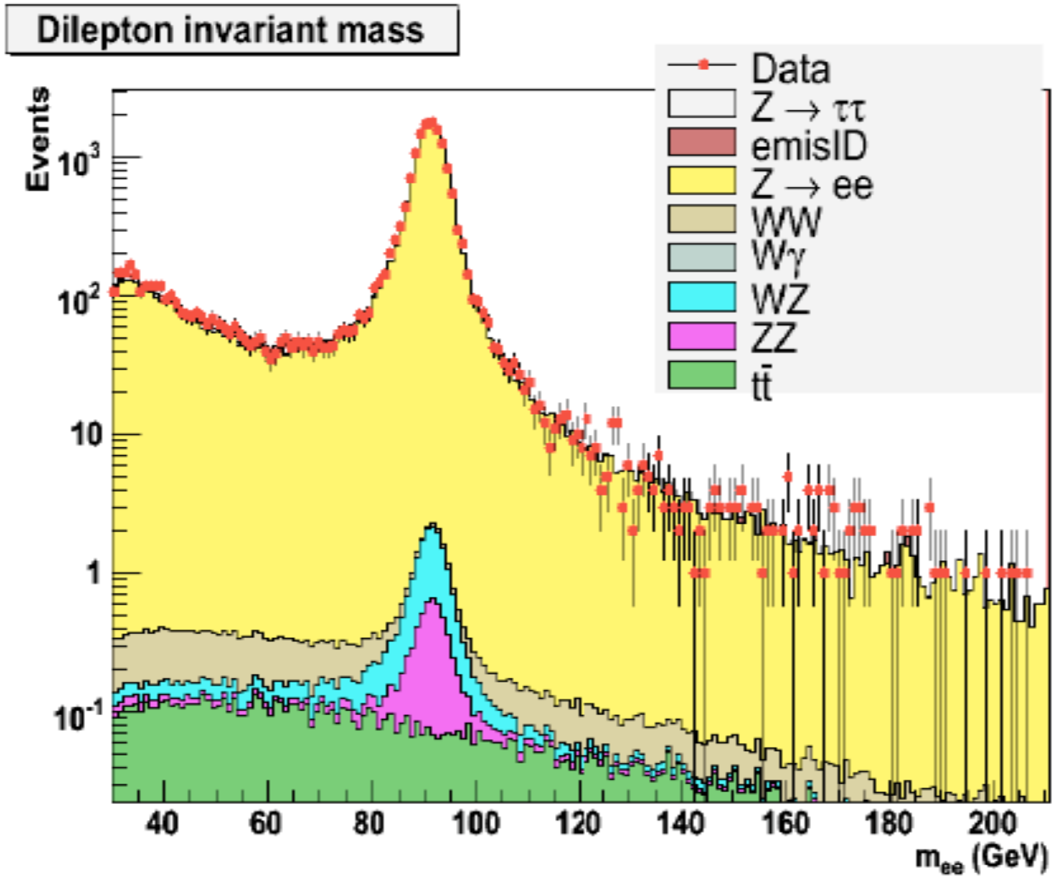


Electron reconstruction



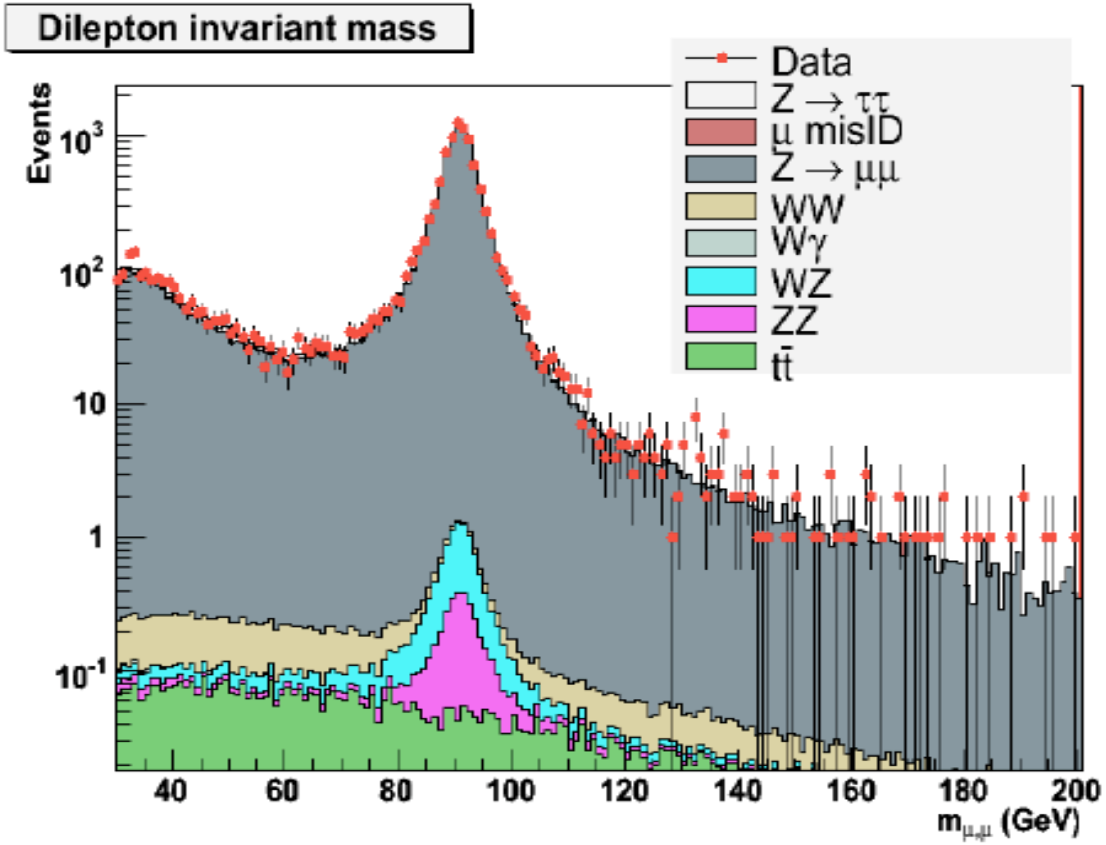
- Central detector
- E_{HAD}/E_{EM}, E/p, and calorimeter cluster lateral shape consistent with the expectation for electrons
- Not a lepton from a conversion pair
- Isolated
- E_T>10 GeV for $\tau_e + \tau_h$
  E_T>8 GeV for $\tau_e + \tau_\mu$

- Electrons are reconstructing by matching **a track and a cluster**



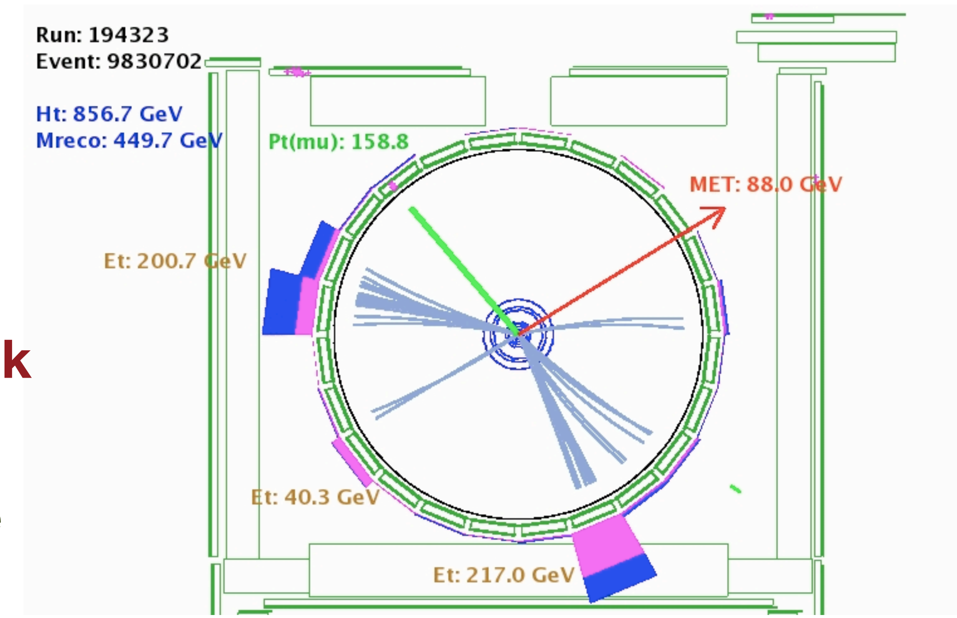
- Good control over efficiencies (including trigger)

Muon reconstruction



- Fiduciality in the central muon chambers
- Small energy deposition in the calorimeter
- $p_T > 10$ GeV for $\tau_\mu+\tau_h$

  $p_T > 8$ GeV for $\tau_e+\tau_\mu$
- Isolation



- Muons are reconstructed by matching **a track with hits** in the muon spectrometer
- Good control over momentum scale and rate (efficiencies)

Outline

- Search motivation:
    - why MSSM and why this channel?
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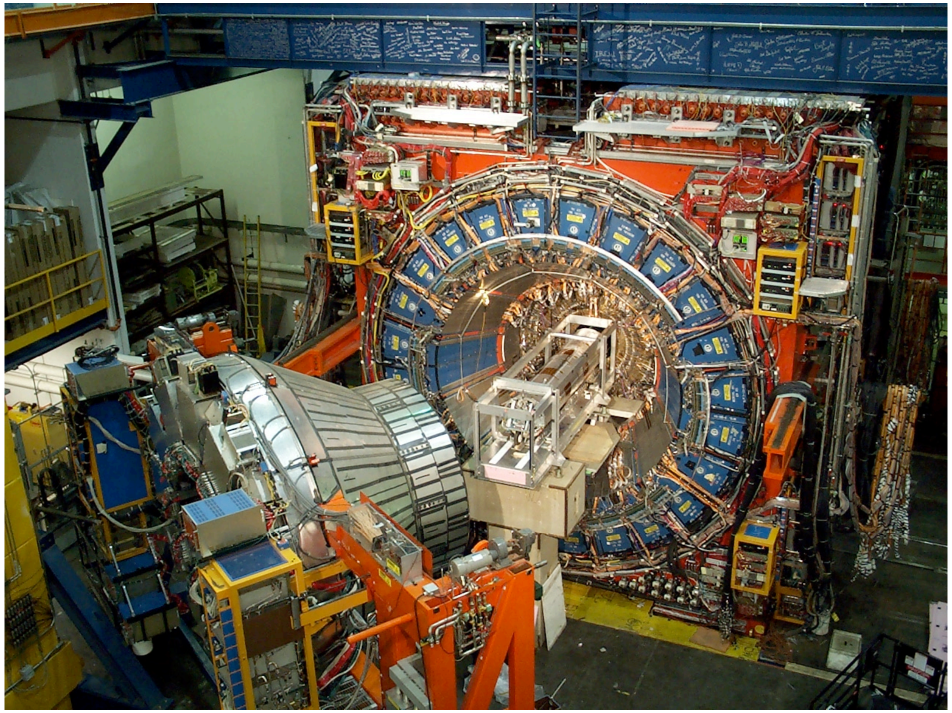
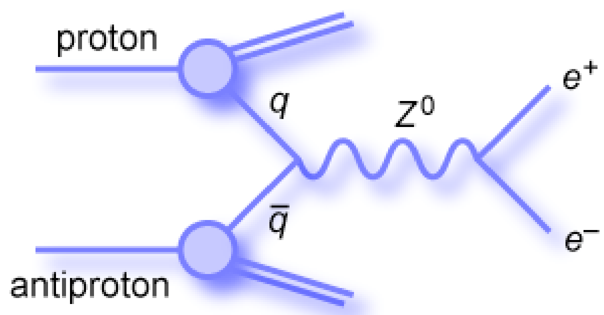
    - how can our detector "see" particles?
- Analysis description
    - Data samples and trigger
    - Particle identification
    - event selection, background estimation and signal acceptance
- Observed events, fit and results
- Conclusions

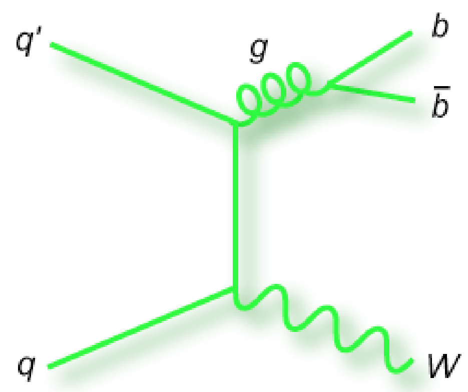


SM as a background: main processes

- $Z/\gamma^* \to \tau\tau$
  - estimated using MC, normalized to luminosity with LO cross section and k-factor for NLO.
  - Largest background
  - Same final state as signal

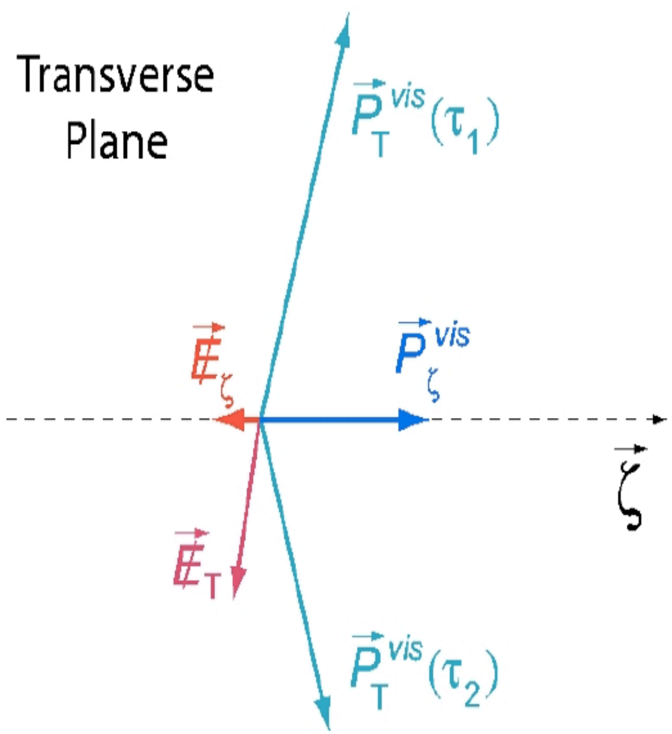


- $Z \to \mu\mu, ee$:
  - estimated using MC, also k-factor for NLO cross section



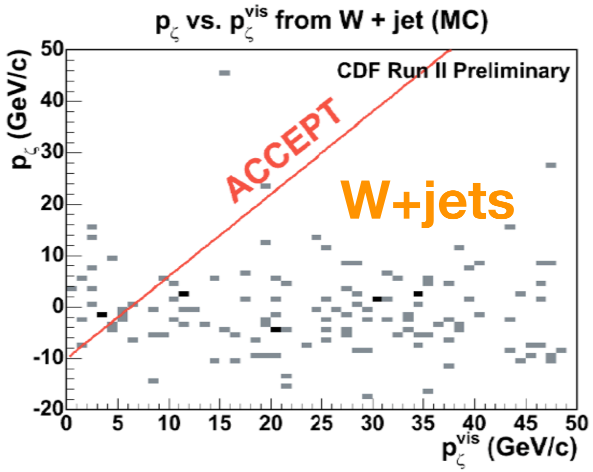
- Misidentified jet as τ_h
  - multi-jet, W+jets; conversion+jet ($\tau_e\tau_h$ only)
  - Shape and normalization estimated from data: fake rate.
- Misidentified or non-isolated e/μ in the $\tau_e\tau_\mu$ channel
  - Shapes and normalization estimated from events in the e/μ isolation sidebands
- Other: estimated using MC (NLO when available)
  - $t\bar{t}$, W, WW, WZ , ZZ, Wγ , Zγ

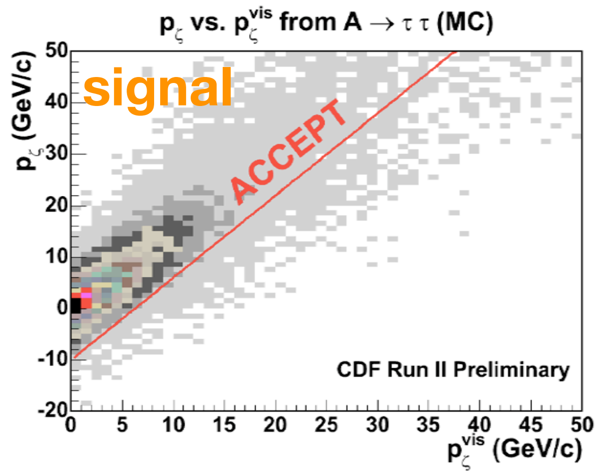
Event selection



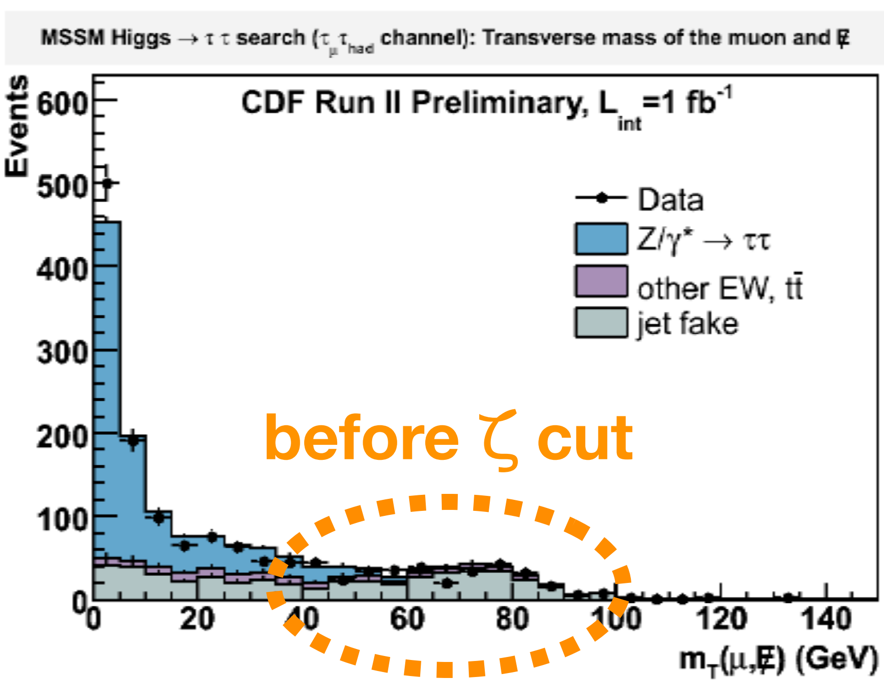
- Events compatible with a ditau signature are selected
- Some extra cuts are applied:
  - both leptons from same vertex
    $|z^0_{\tau 1} - z^0_{\tau 2}| < 5$ cm
  - vertex in the "luminous" region
    $|z^0_{\tau 1} + z^0_{\tau 2}| < 60$ cm
  - angle between taus sufficiently large
    $\Delta\varphi(\tau_1,\tau_2) > 0.5$ rad
- Low p_T QCD suppressed with H_T cut
  - $\tau_e+\tau_h$, 1prong: $H_T=|p_T(\tau_h)|+|E_T(e)|+|\not{E}_T| > 50$ GeV
  - $\tau_\mu+\tau_h$, 1prong: $H_T=|p_T(\tau_h)|+|p_T(\mu)|+|\not{E}_T| > 45$ GeV
  - $\tau_\ell+\tau_h$, 3 prong: $H_T > 55$ GeV
  - $\tau_e + \tau_\mu$: $H_T = |p_T(\mu)|+|E_T(e)| > 30$ GeV
- ζ cut: di-boson, ttbar, W+jet suppression

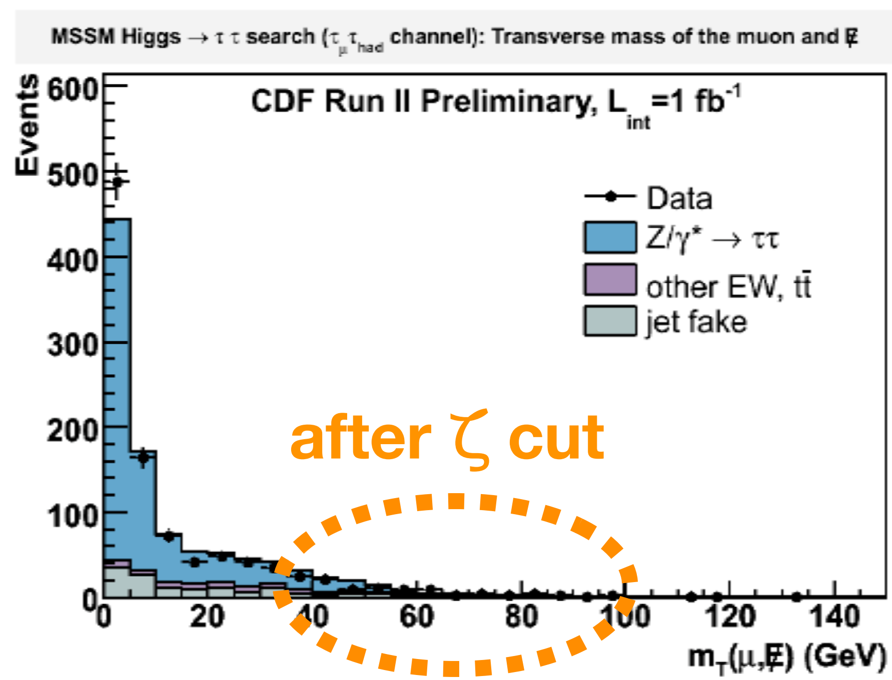
Background suppression: zeta cut





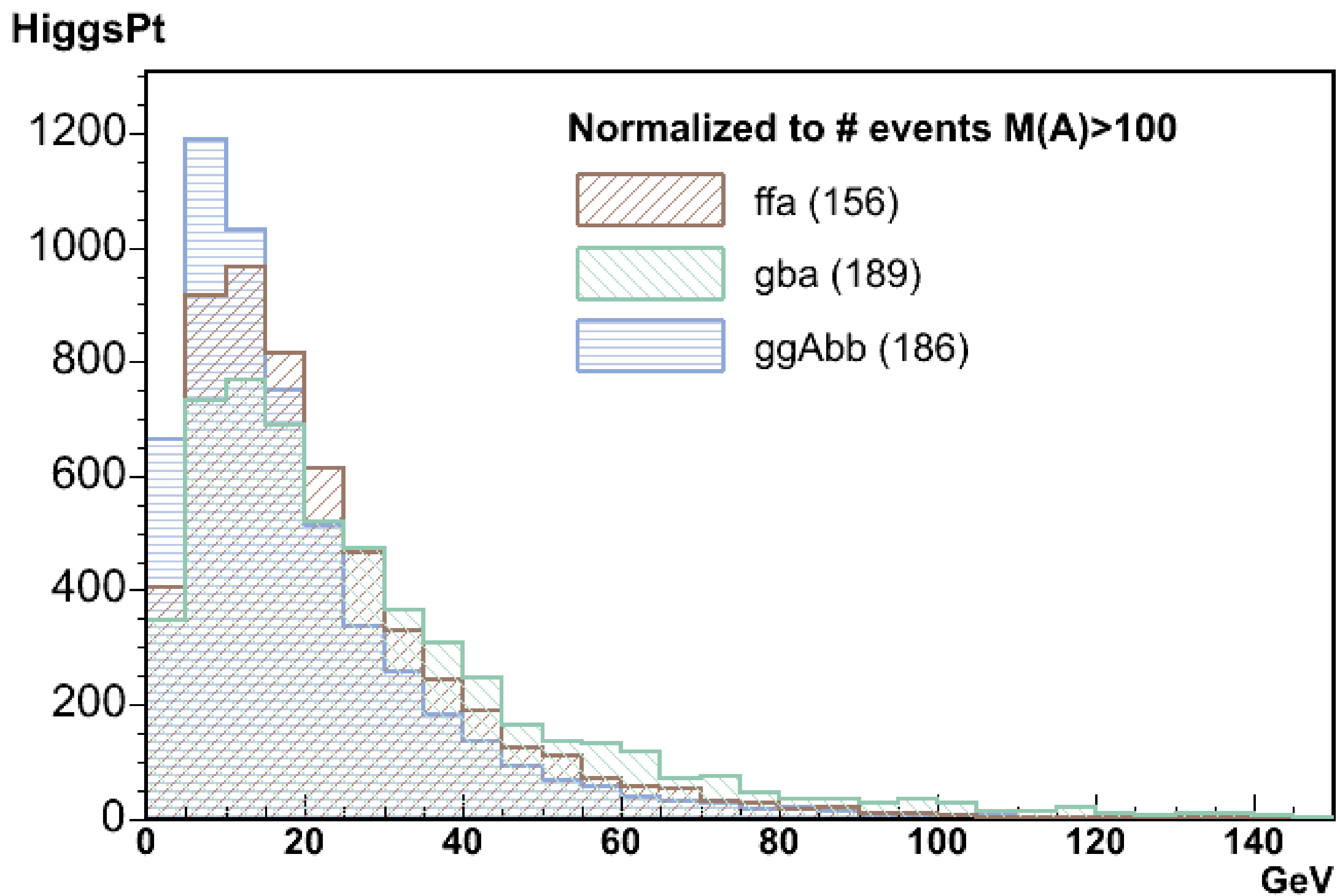
- ζ: bisection of $\Delta\varphi(\tau_1,\tau_2)$
  $p_\zeta = (p_T^{\tau 1}+p_T^{\tau 2}+\not{E}_T) \cdot \zeta n$
  $p_\zeta^{vis} = (p_T^{\tau 1}+p_T^{\tau 2}) \cdot \zeta n$
- **$p_\zeta > 1.6\, p_\zeta^{vis} - 10$**





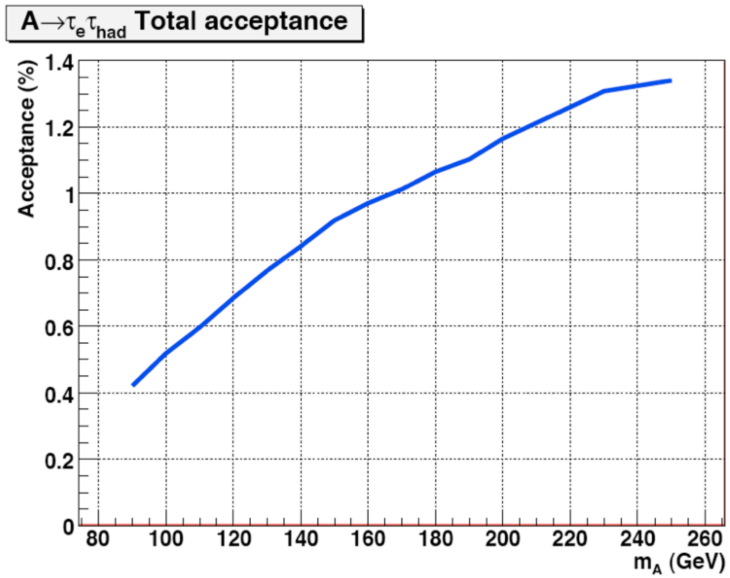
MSSM Higgs signal samples

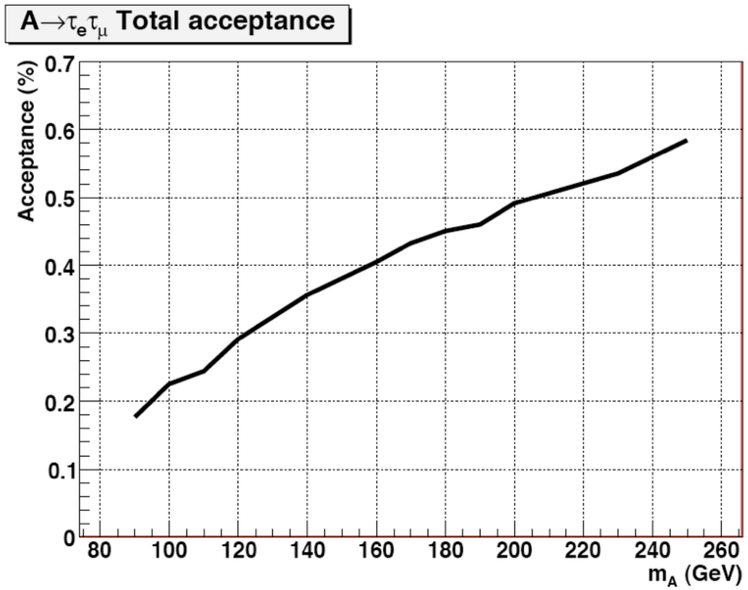
- Processes generated with PYTHIA.
- **14** mass points scanning Higgs masses from **90 to 250 GeV**. Both production mechanisms.
- PYTHIA had to be tuned to produce the “right” p_T spectrum for Higgses and **recoiling b-quarks**.

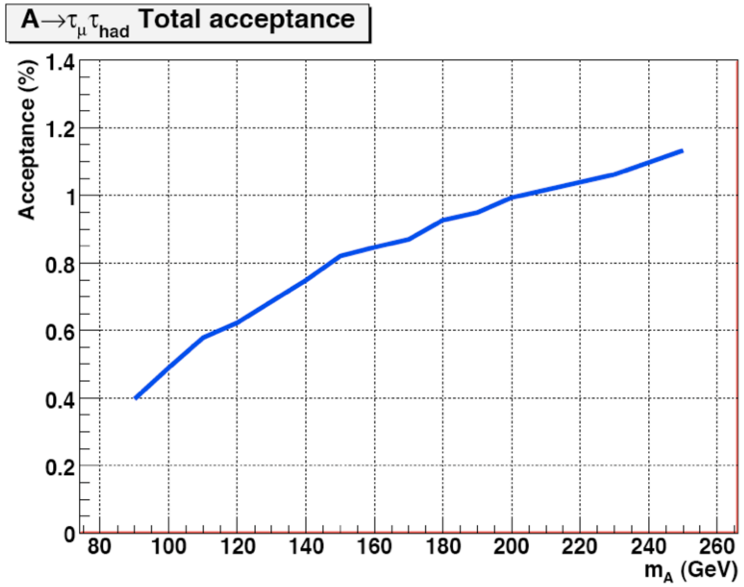


- Before the fix, “matrix element” and “parton showering” approaches showed different shapes.
- This fix had been implemented and tested in Z+jets

Signal acceptance







- Acceptances **include tau branching** ratios
- **Both production mechanisms** used and weighted according to expected relative cross sections
- Overall: **~1%** at low mass and **~3%** at high mass

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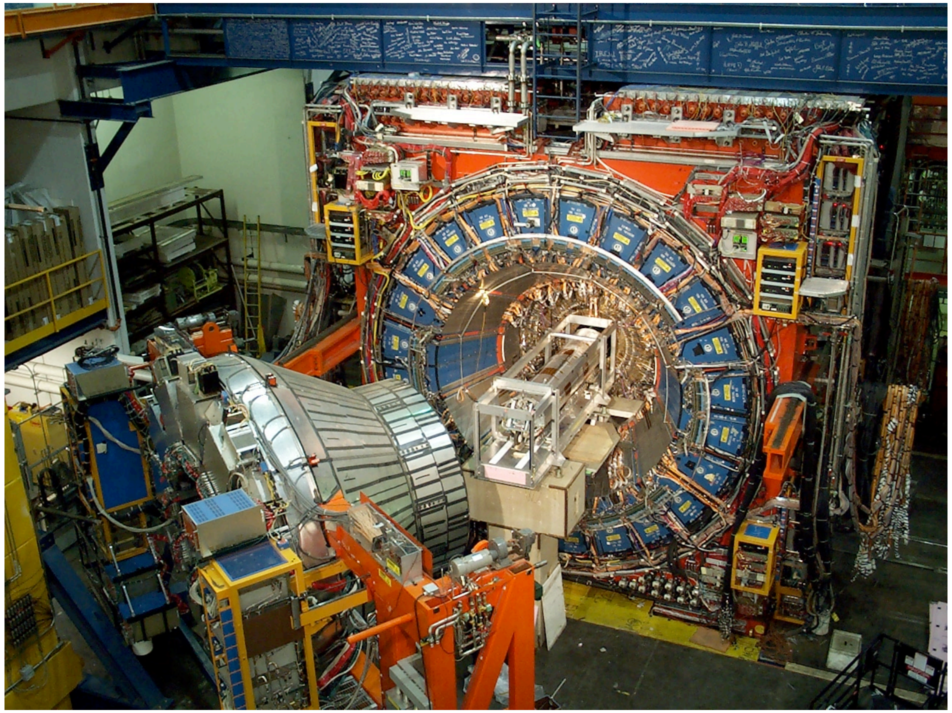
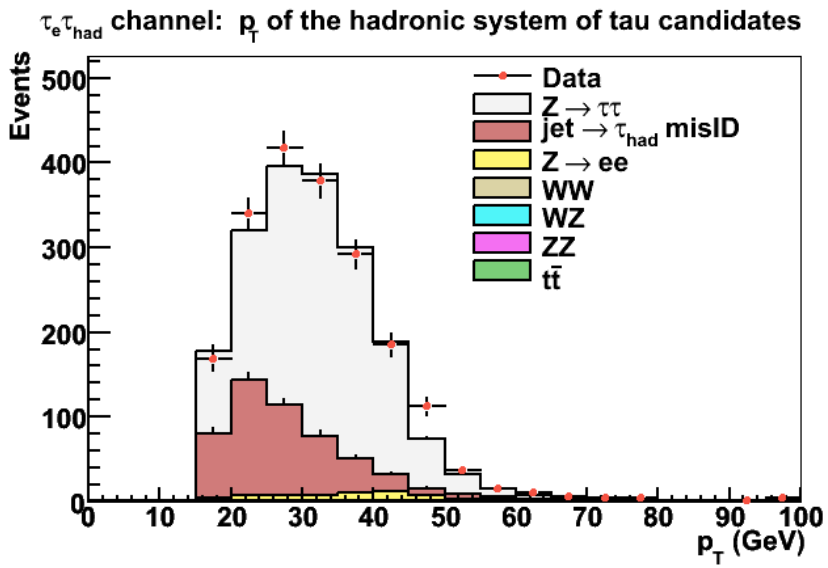


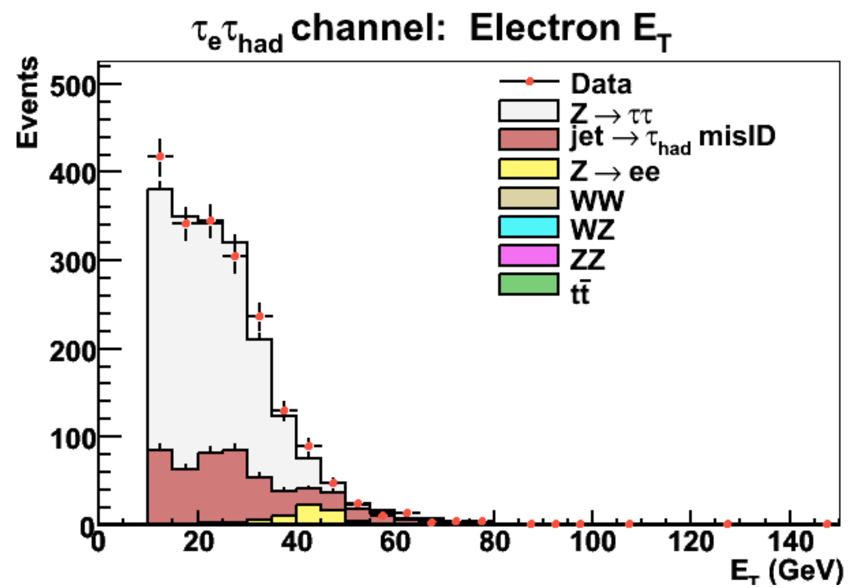
$\tau_e\tau_h$ signal region event count

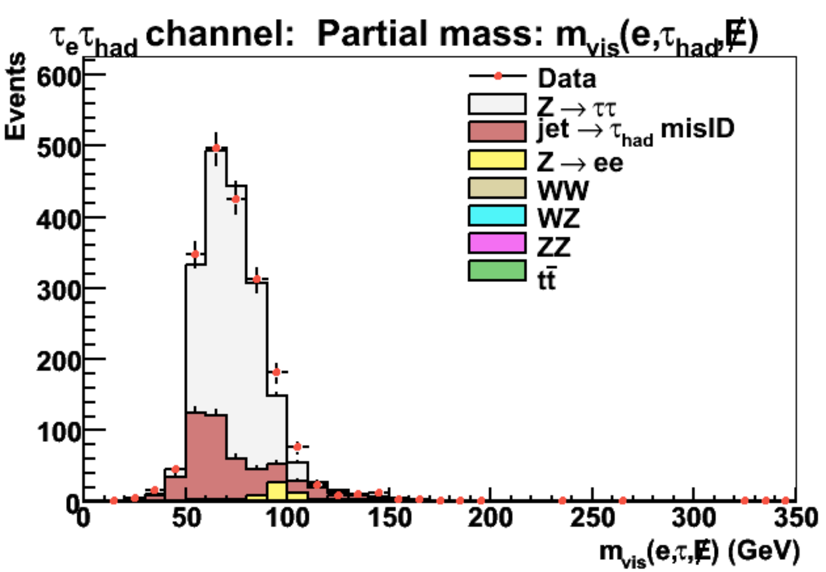
source	Number of events
$Z\to\tau\tau$	1376.9 ± 8.3
$Z \to ee, \mu\mu$	69.7 ± 2.0
$W/Z+\gamma$, di-boson	4.3 ± 0.1
tt	3.7 ± 0.1
Jet$\to\tau$ fakes	466.5 ($\pm$ 15% sys)
Total ALL bg	1921.1 ± 8.5
Observed	1979

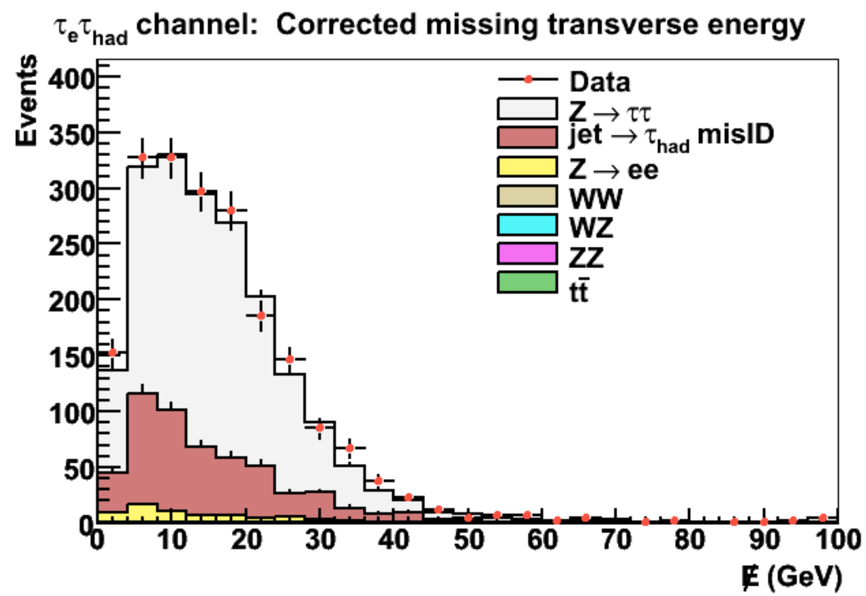
- For $\tan\beta$=40, m_A=140 GeV: ~35 expected signal events

$\tau_e\tau_h$ signal region distributions









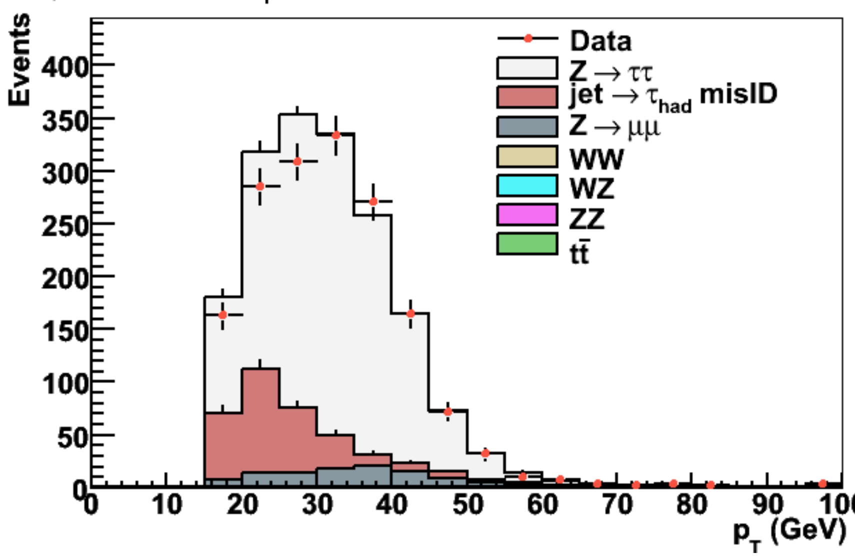
$\tau_\mu \tau_h$ signal region event count

source	Number of events
$Z \to \tau\tau$	1353.7 ± 8.1
$Z \to ee, \mu\mu$	107.3 ± 2.3
W/Z+γ, di-boson	3.3 ± 0.1
tt	3.0 ± 0.1
Jet→τ fakes	283.6 (± 15% sys)
Total ALL bg	1750.8 ± 8.5
Observed	1666

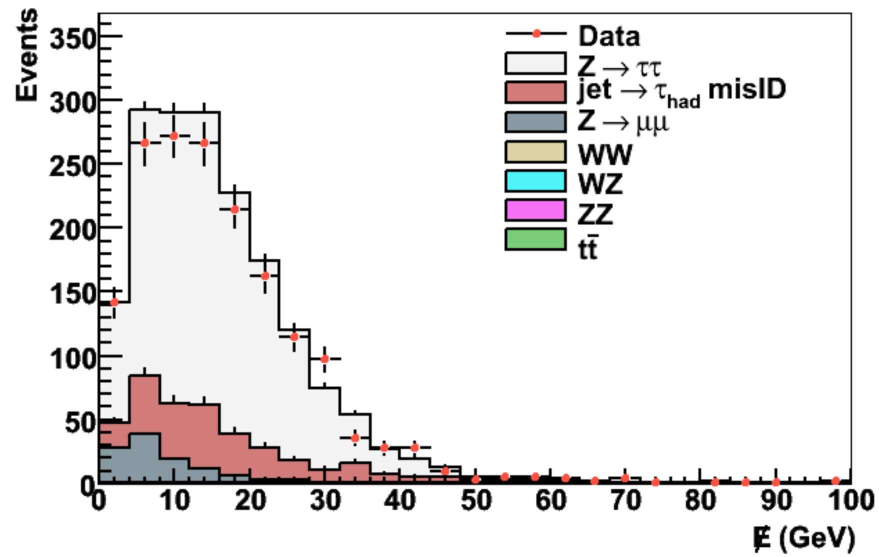
- For tanβ=40, m_A=140 GeV: ~30 expected signal events

$\tau_\mu\tau_h$ signal region distributions

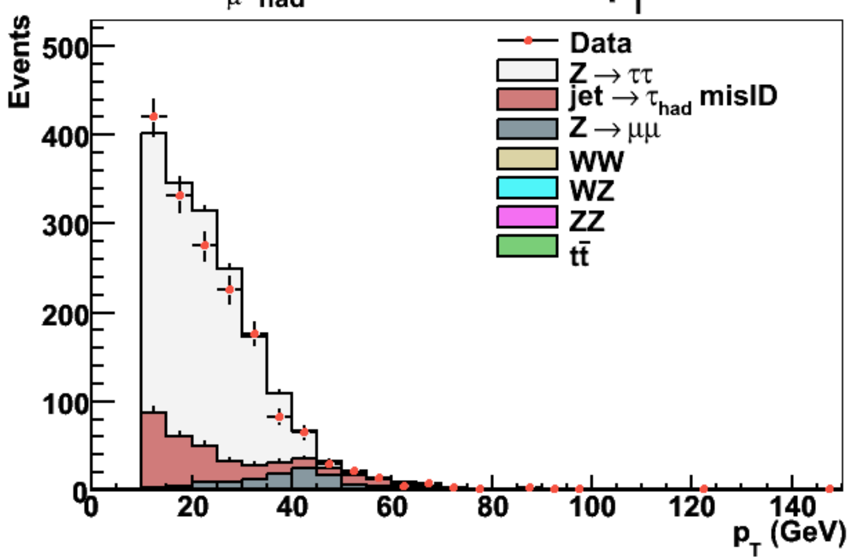
$\tau_\mu\tau_{had}$ channel: p_T of the hadronic system of tau candidates



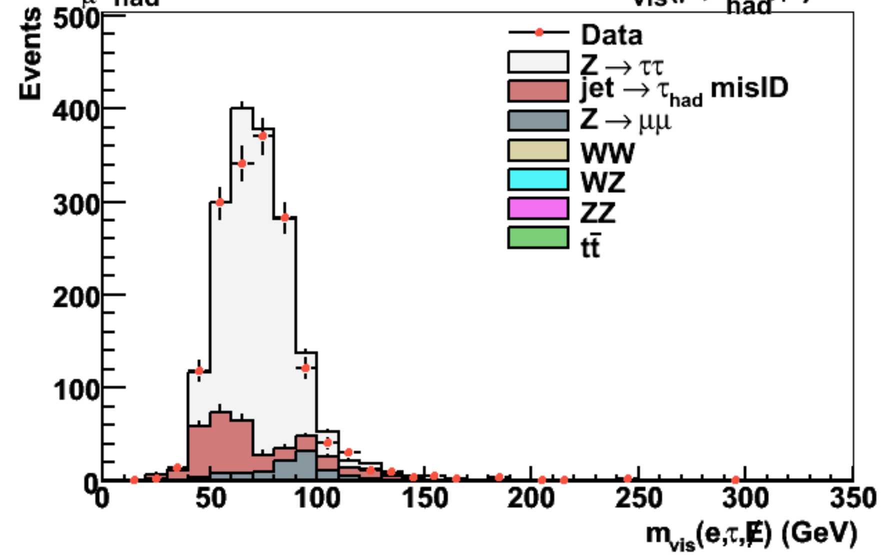
$\tau_\mu\tau_{had}$ channel: Corrected missing transverse energy



$\tau_\mu\tau_{had}$ channel: Muon p_T



$\tau_\mu\tau_{had}$ channel: Partial mass: $m_{vis}(\mu,\tau_{had},\not{E})$

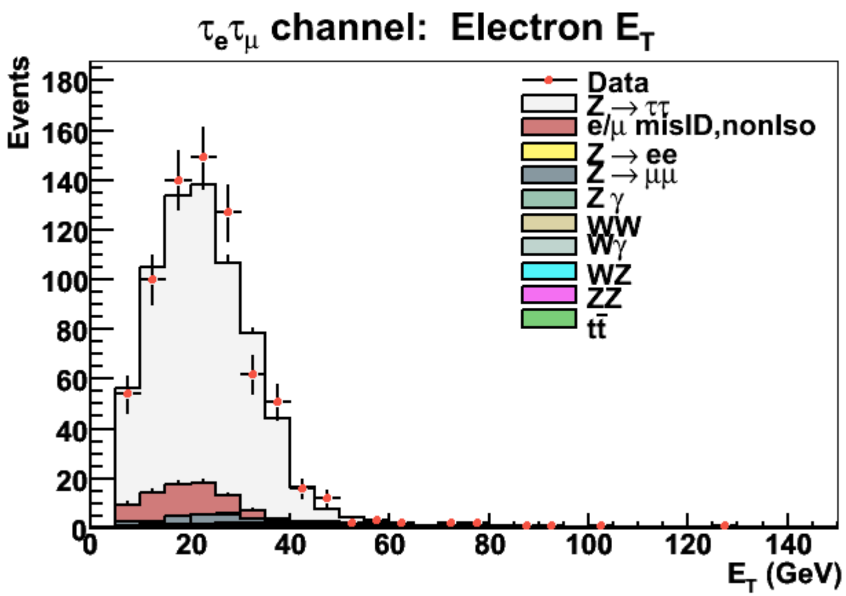


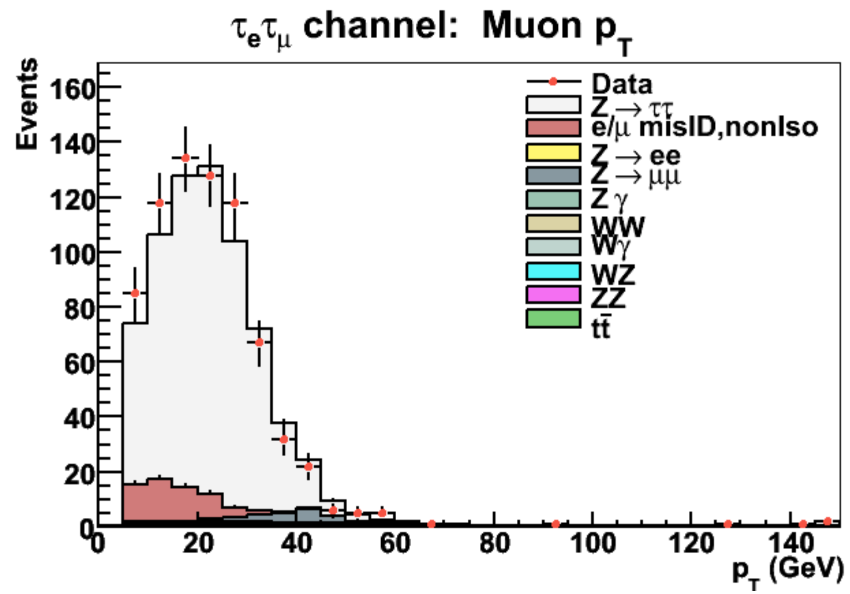
$\tau_e\tau_\mu$ signal region event count

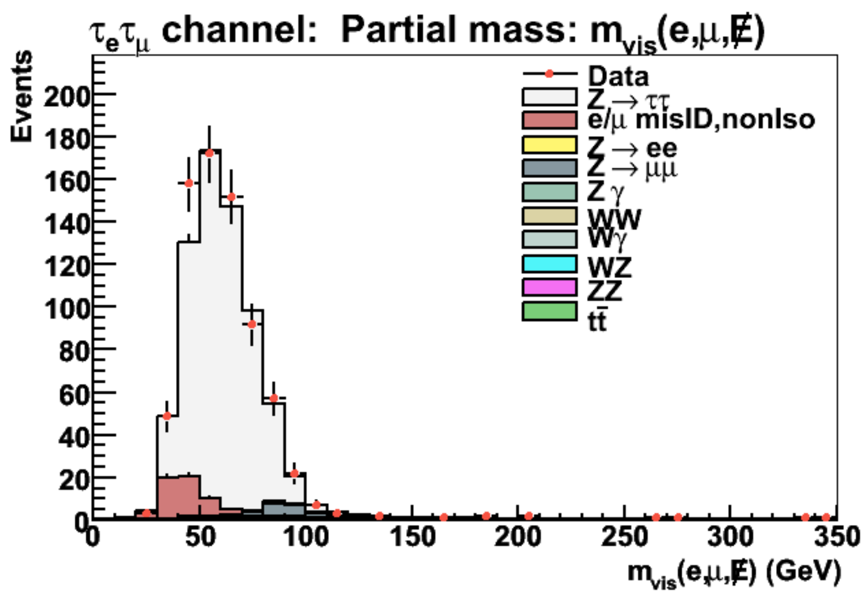
source	Number of events
$Z\to\tau\tau$	604.8 ± 5.5
$Z \to ee$	1.5 ± 0.4
$Z \to \mu\mu$	17.7 ± 0.9
W/Z+γ, di-boson	11.4 ± 0.1
tt	9.1 ± 0.1
Fake/non-isolated	57.3 ± 3.3
Total bg	701.9 ± 6.5
observed	726

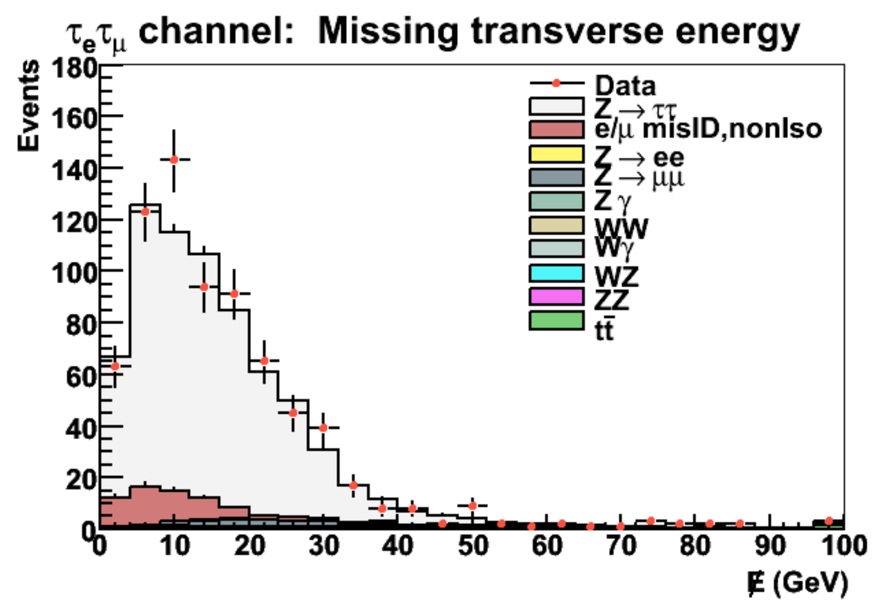
- For tanβ=40, m_A=140 GeV: ~14 expected signal events

$\tau_e\tau_\mu$ signal region distributions

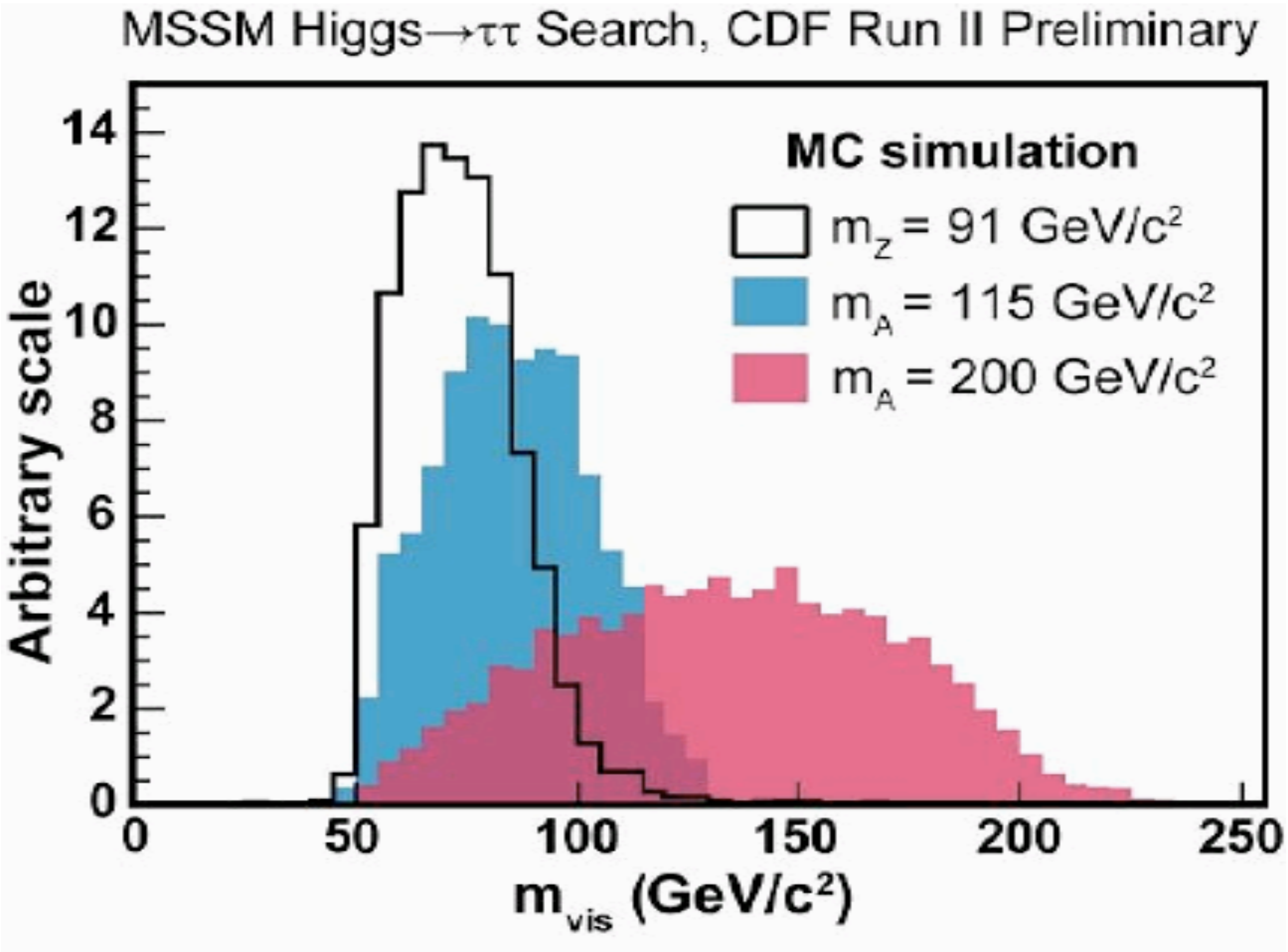








Signal extraction: discriminating variable



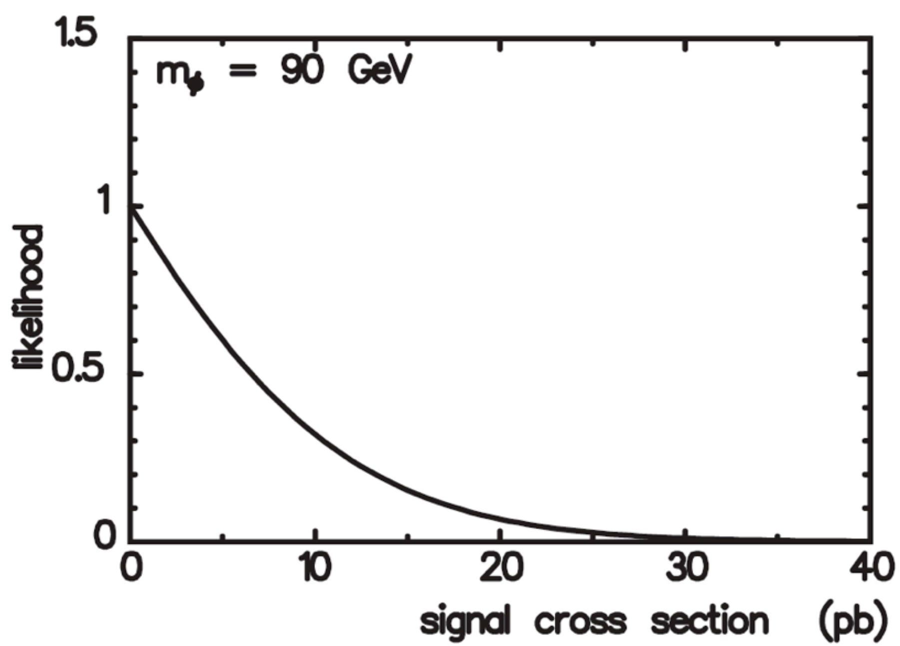
- Better signal/background discrimination using shapes, instead of counting.
- Discriminating variable:
  - **Visible mass**: the mass of the sum four vector of the decay products of the taus and $\not{E}_T$

Fitting procedure: profile likelihood

1. Generate templates of the different background contributions to each channel, ie, the **m_{vis} distribution** of $Z\to\tau\tau$ in the $\tau_e+\tau_h$ channel.
2. Define a **likelihood function** including gaussian constraints on the nuisance parameters, the systematic errors.
3. We maximize the likelihood, for different amounts of signal (**signal scan**)
4. The cross-section for which a **95% of the probability** is integrated defines the exclusion limit.
5. Expected limits are calculated generating **pseudo-experiments** with no signal and minimizing the likelihood. The median is the expected limit

$$\mathcal{L} = \prod_{ij} \frac{\mu_{ij}^{n_{ij}} e^{-\mu_{ij}}}{n_{ij}!} \times G(L, L_0, \sigma_L) \times \ldots$$

$$\mu_{ij} = \sum_k L \sigma_k \epsilon_{ijk}$$

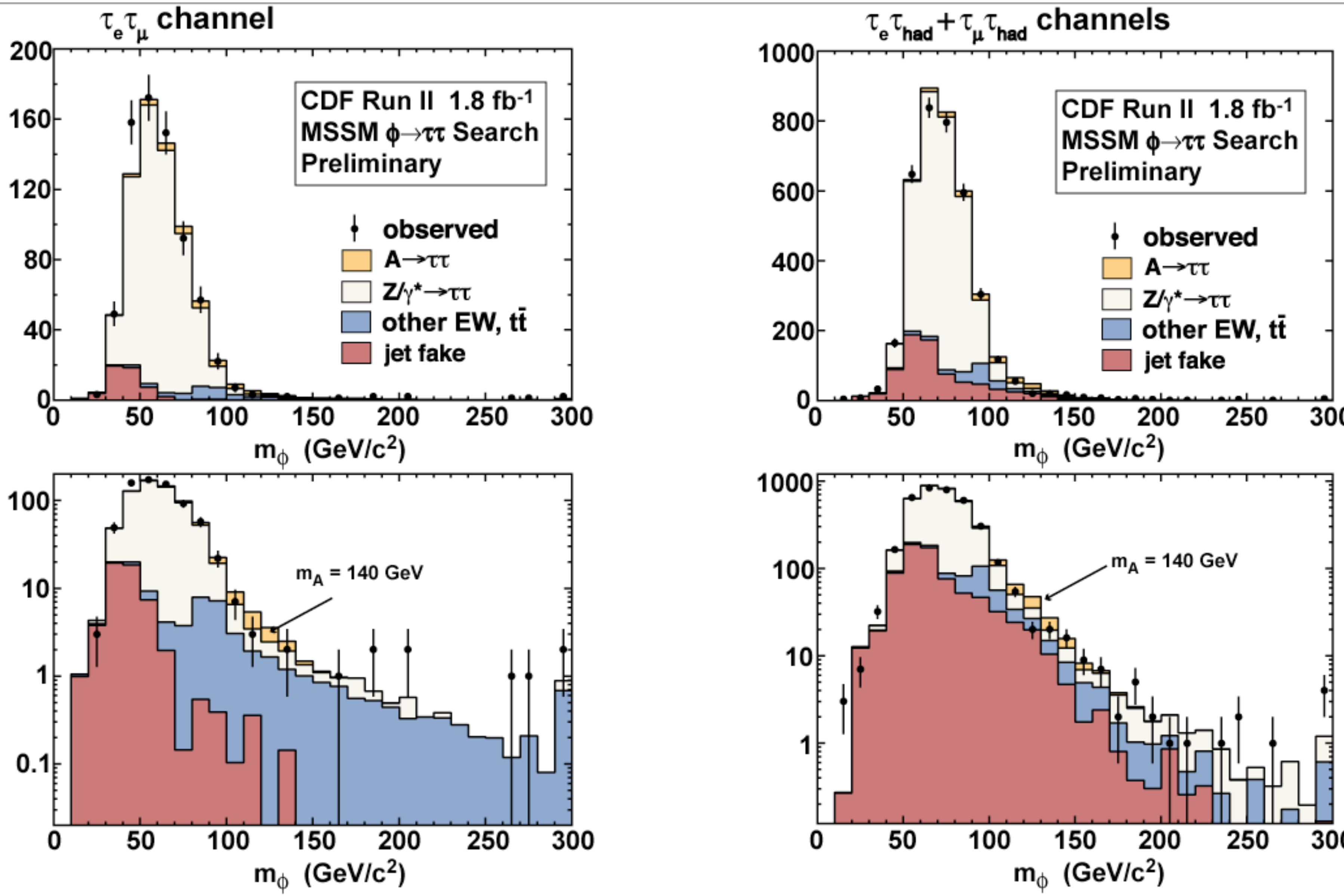


Systematic errors: nuisance parameters

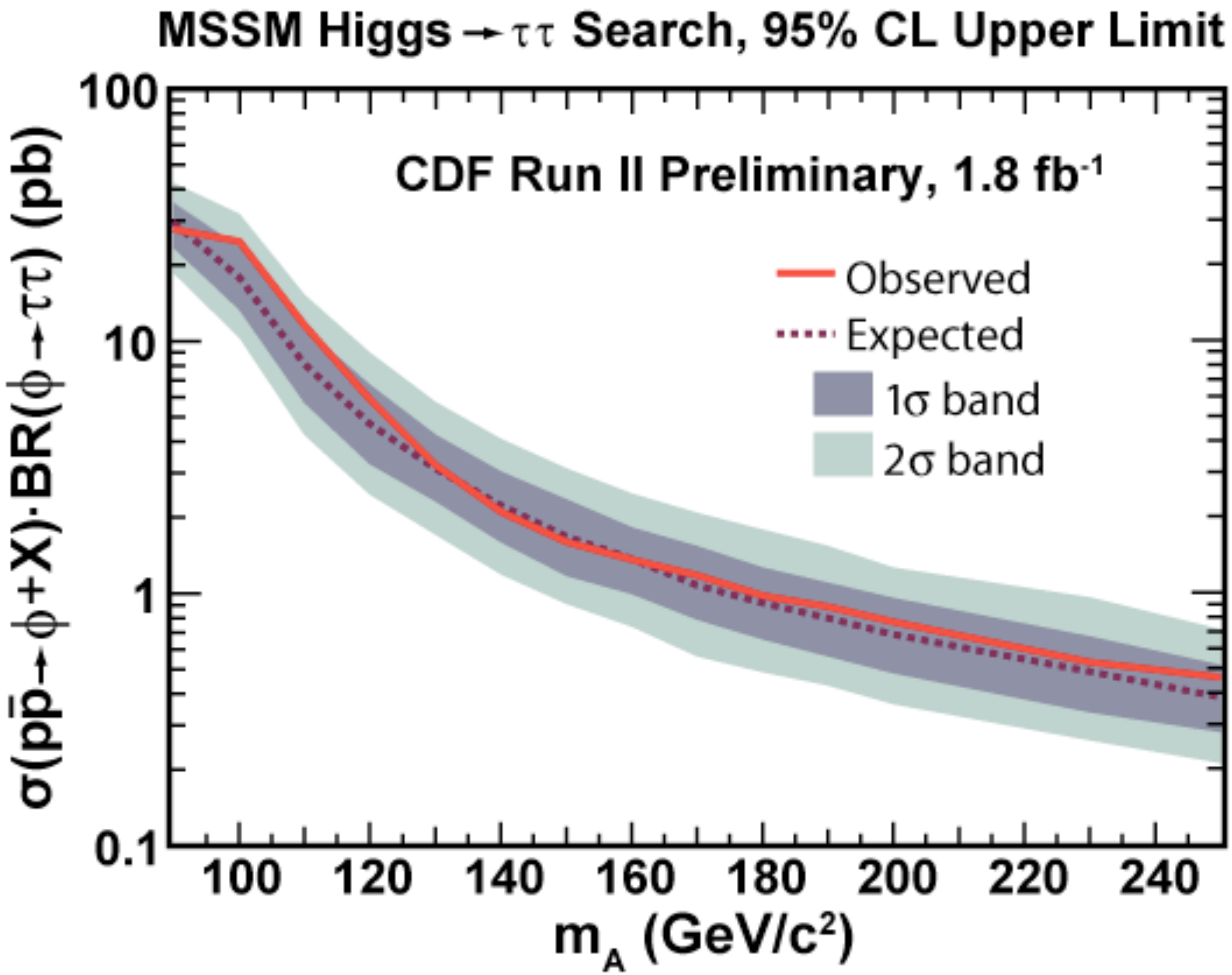
Parameter	type	Error(%)	applies to:
e ID	rate	2.4	e in MC
muon reco+ID	rate	2.6	μ in MC
tau ID	rate	3.0	τ in MC
e trig	rate	0.3	e in MC
muon trig	rate	1.0	μ in MC
tau trig	rate	3.0	τ in MC
z-vertex cut	rate	0.5	all MC
fake/non-iso lepton bg in $\tau_e\tau_\mu$	rate	20.0	fake/non-iso bg
fake τ_{had} in $\tau_e\tau_{had}$	rate	15.0	fake tau bg
fake τ_{had} in $\tau_\mu\tau_{had}$	rate	15.0	fake tau bg
$\sigma \times \mathcal{B}(Z \to ll)$	rate	2.2	Z MC
$Z \to ll$ backgrounds	rate	6	$\tau_{e/\mu}\tau_{had}$
$\sigma(t\bar{t})$	rate	13.4	$t\bar{t}$ MC
di-boson cross sections	rate	10	di-boson MC
PDFs ($Higgs$)	rate	5.7	signal
Luminosity	rate	6.0	all MC
JES	shape	$\pm 1\sigma$ (per jet)	all MC
EM scale	shape	± 1.0	e in MC
Tau p_T scale	shape	± 1.0	τ_{had} in MC

- Systematic uncertainties affecting the shapes are handled with a **morphing** technique
- All **systematics** are included as **nuisance parameters** in the fit
- **Gaussian constraints** in the likelihood

Fitted distributions for m_A = 140 GeV



95% CL exclusion limit on σ x BR

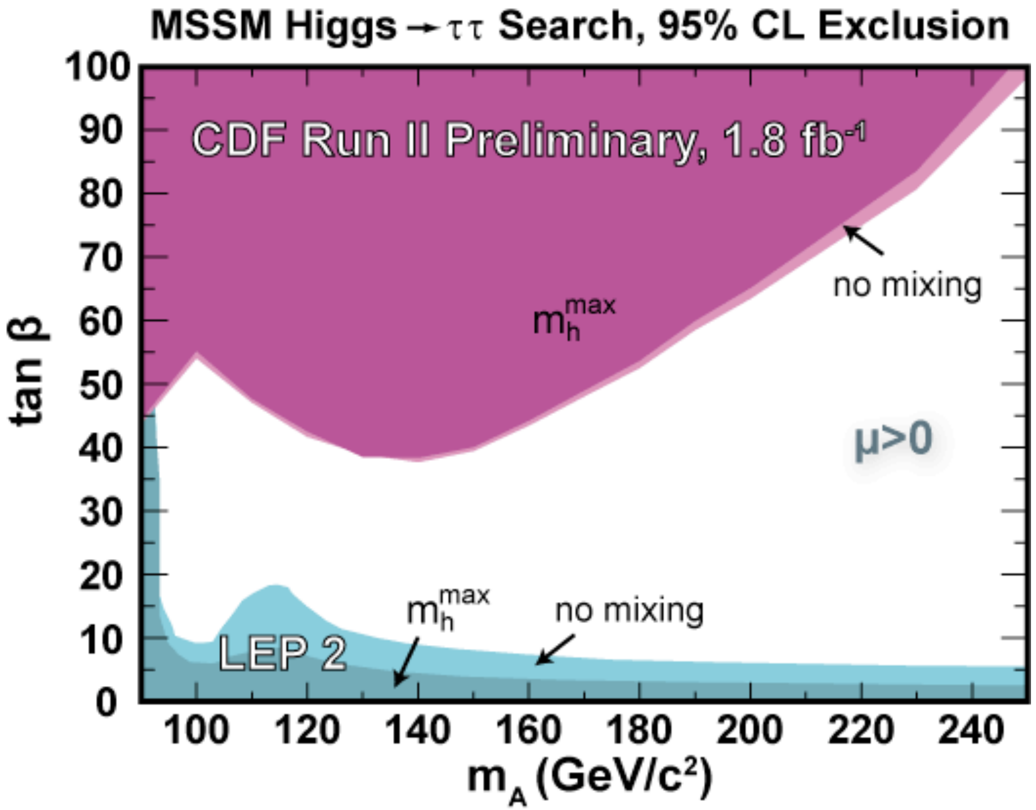


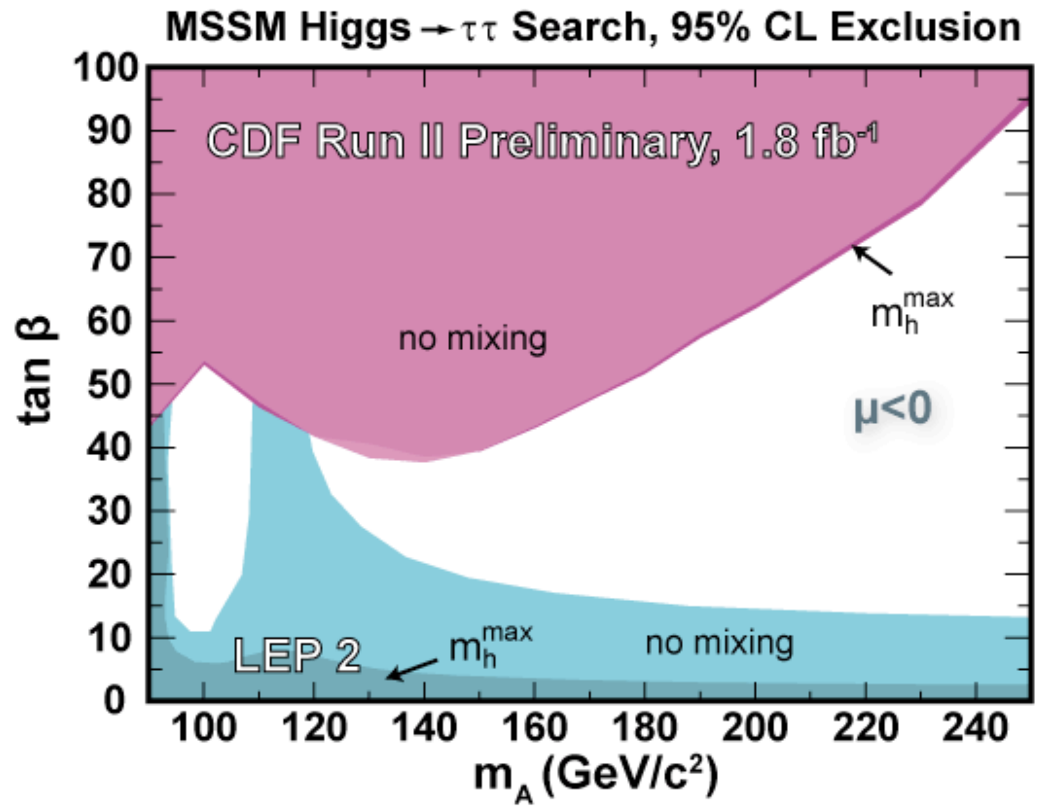
- Cross section times branching ration limits range from **30 pb** for a Higgs mass of 90 GeV to **0.4 pb** for 250 GeV
- Observed and expected limits are very similar, within 1σ band
- Sensitivity is limited by systematic uncertainties

Interpretation of the limit in MSSM

- Limits are translated into 4 different scenarios (Carena et al):
  - **m^{max}**: maximum mass of the Higgs for a given tanβ.
  - **no-mixing**: no mixing in the stop sector.
  - Both scenarios are considered for μ=±200 GeV (Higgs mixing parameter)
- **SM cross sections** taken from Kilgore (bb, 2003) and HIGLU (Spira, gg, 1997)
- **MSSM enhancement** factor with FeynHiggs (Heinemeyer, 2000). This takes into account radiative corrections
- **Branching ratio** also calculated with FeynHiggs

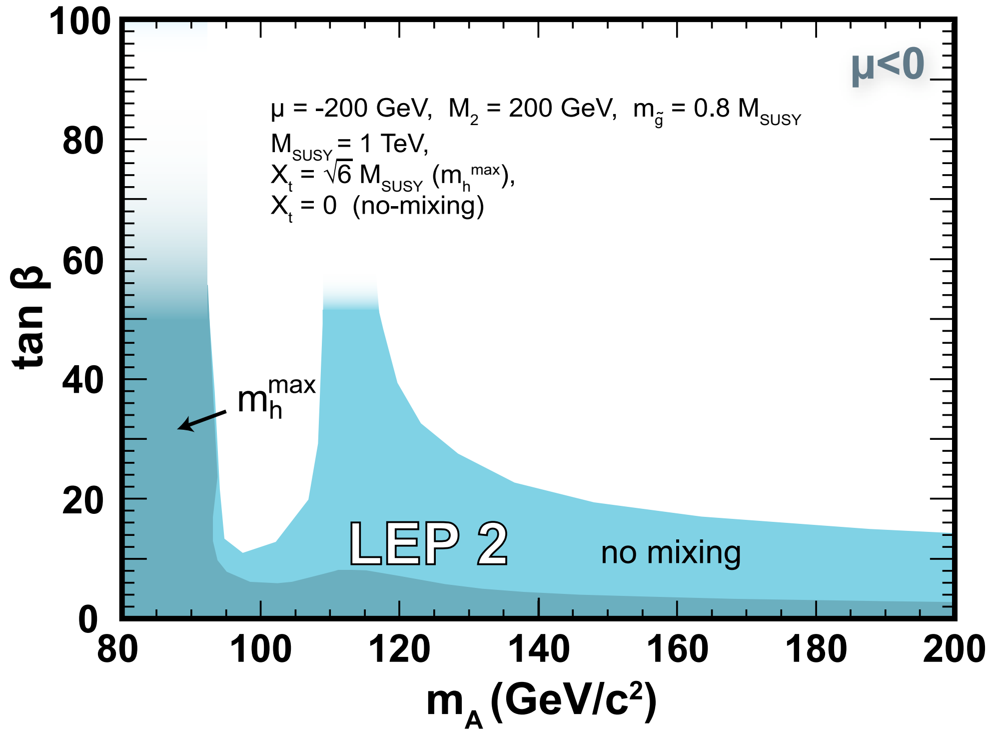
Limits in m_A *vs* $\tan\beta$

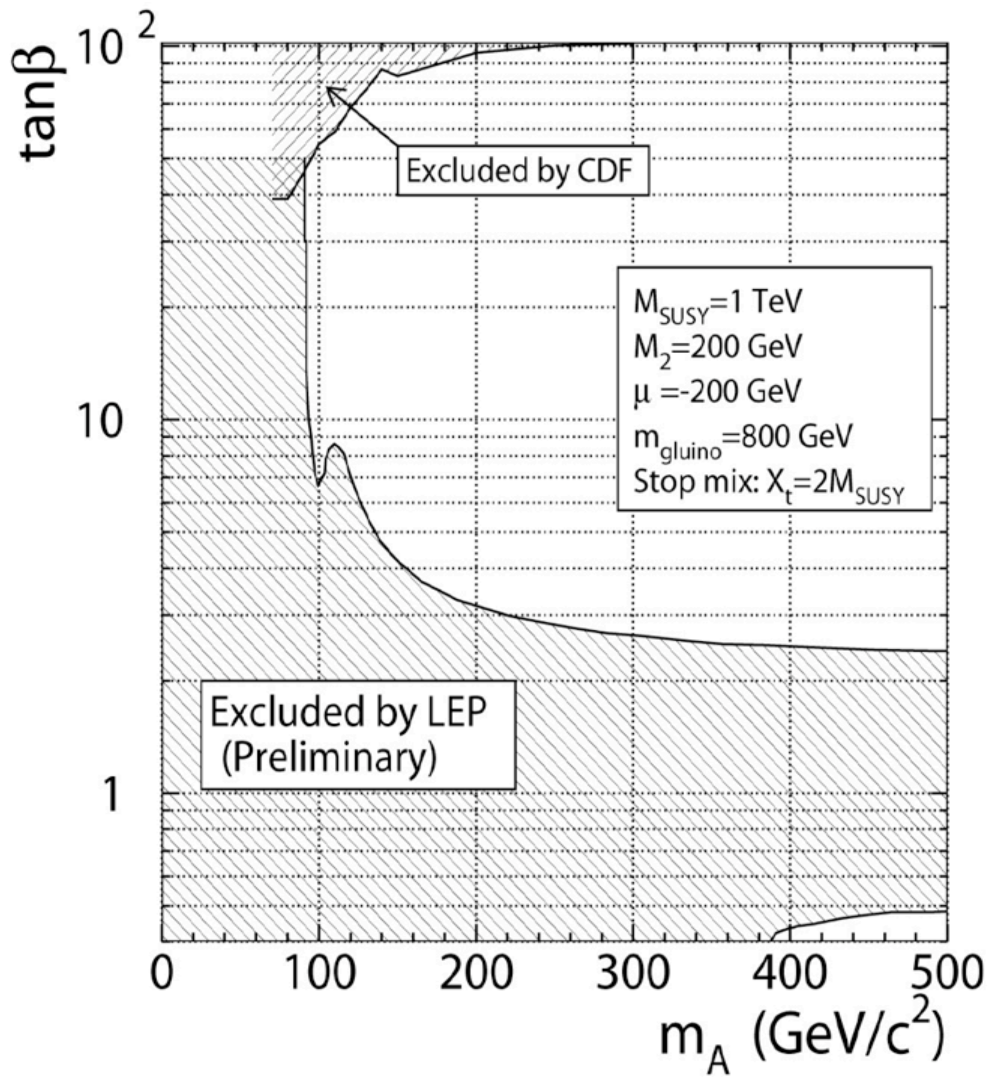




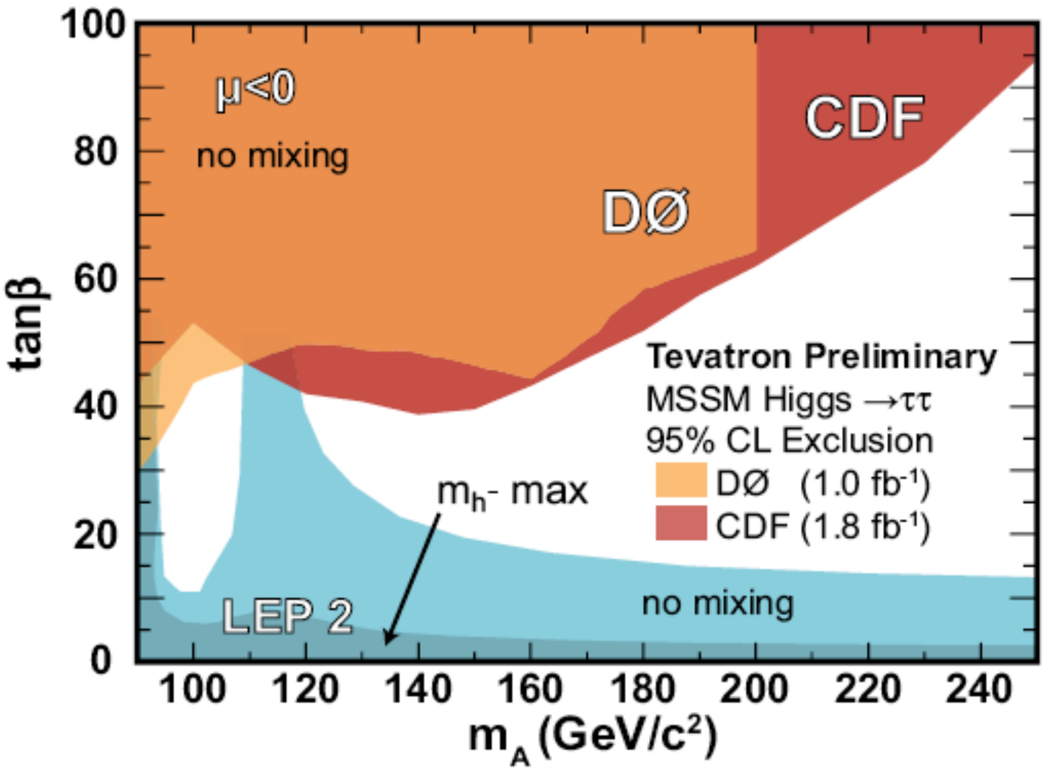
Previous limits on MSSM Higgs

- Set of featured scenarios
- Previous results
  - **CDF**, Run I
  - **LEP**



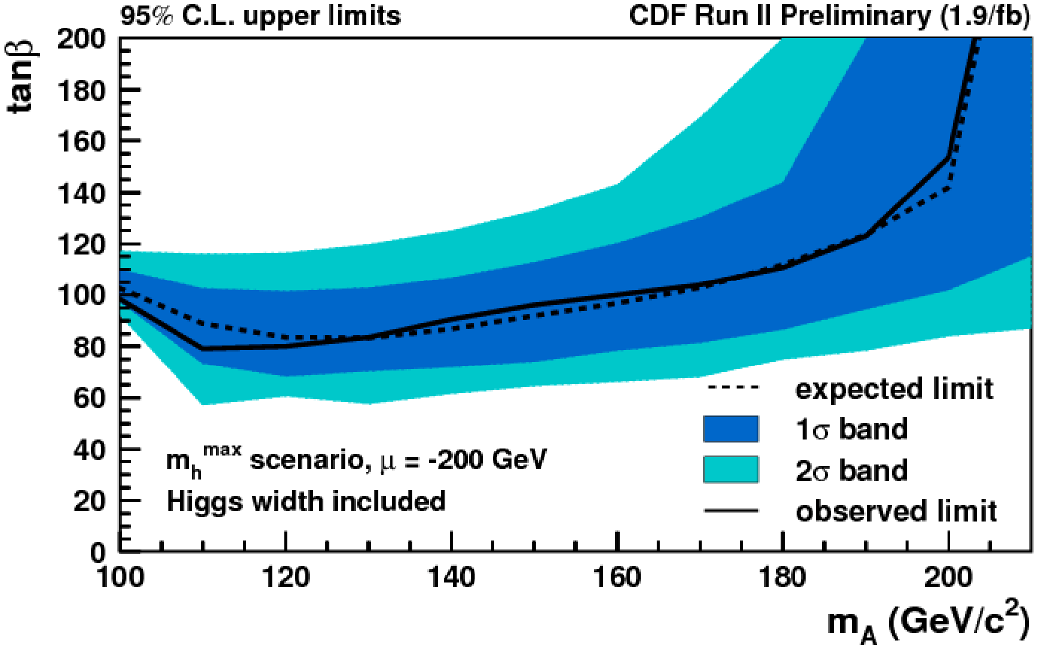


Other results



- CDF result together with D0, as published by **PDG**

- **Latest CDF** result on the search for neutral MSSM Higgs in the **bbb(b)** channel



Conclusions

- This is the **most sensitive** analysis to **neutral MSSM Higgs** bosons at the Tevatron (for now....)
- Currently, this search sets the **most stringent** limits on MSSM Higgs sector at high tanβ
- New implementations improved previous results:
  - better parameterization of **fake rates**: reduction of QCD systematic uncertainty
  - more accurate calculation of the **trigger efficiency**: better estimation in new luminosity regime
  - production of new **MC samples**: improved understanding of the boson boost and underlying event.
  - **larger datasets** (including dynamic pre-scaling and luminosity enabled paths)
- Already probing (and excluding) **tanβ=40** for some range of **m_A**

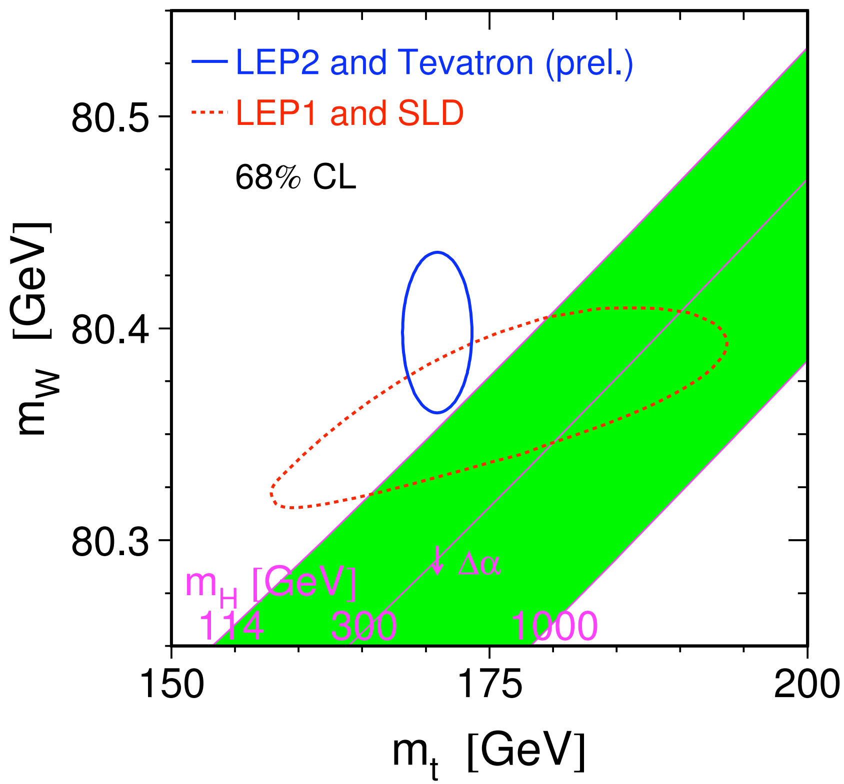
Conclusions

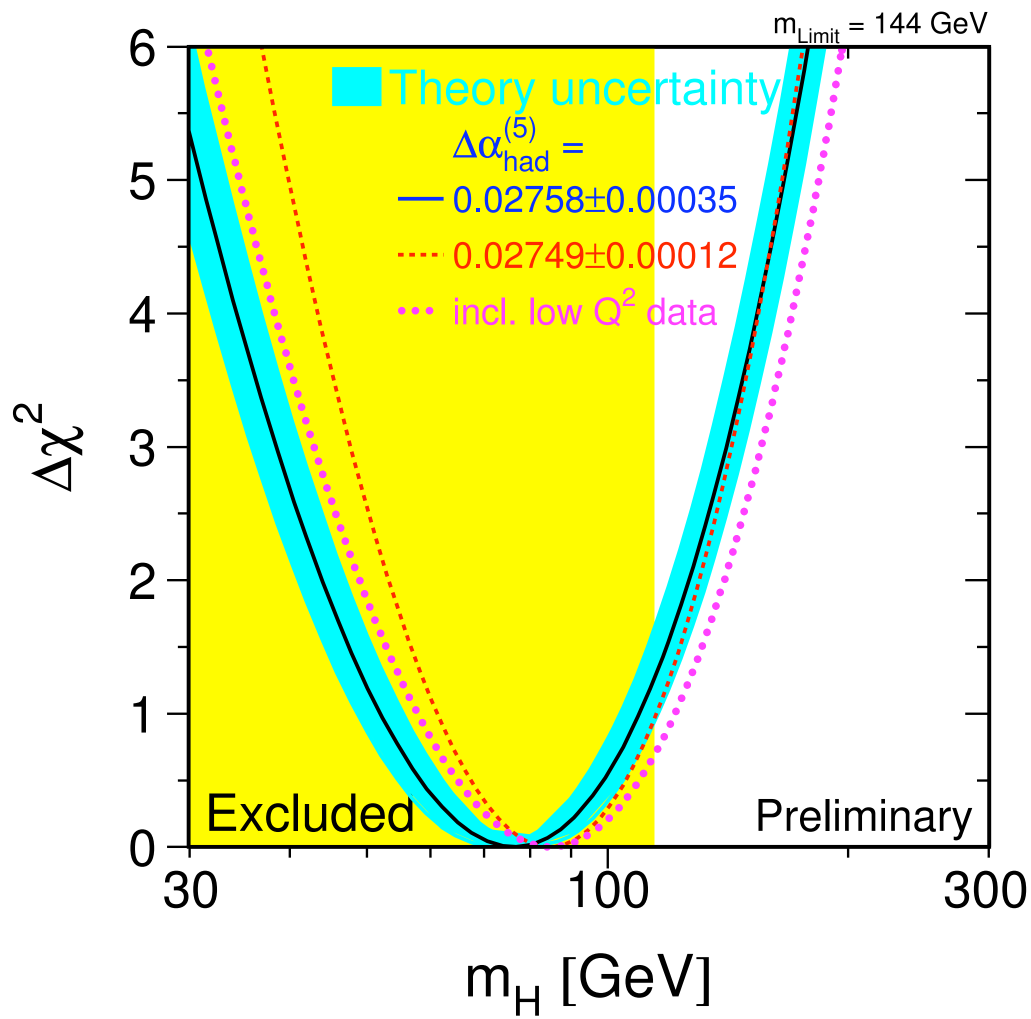
- **Promising future for these searches**: more channels and better signal extraction
  - reconstruction of full mass
  - use multivariate techniques
  - split in exclusive channels
- **New techniques** developed for this analysis can be used in other analysis:
  - have just been **exported** to SM Higgs searches with taus (2 taus + 2 jets)
- Very soon **ATLAS will start taking data**:
  - a much better detector together with larger luminosity and increased CM energy will open the exploration to new regions of the parameter space ... and also new challenges!!!
- Result already in **PDG**. **Paper** is coming soon. It's time for **discovery!!!**

backup

Constraints on the SM Higgs mass

- Global fit with Tevatron's
  m_{top} = **170.9 ± 1.8 GeV** and
  m_W = **80.398 ± 0.025 GeV**
- m_H = **76^{+33}_{-24} GeV**
- m_H < **144 GeV** @ 95 % CL



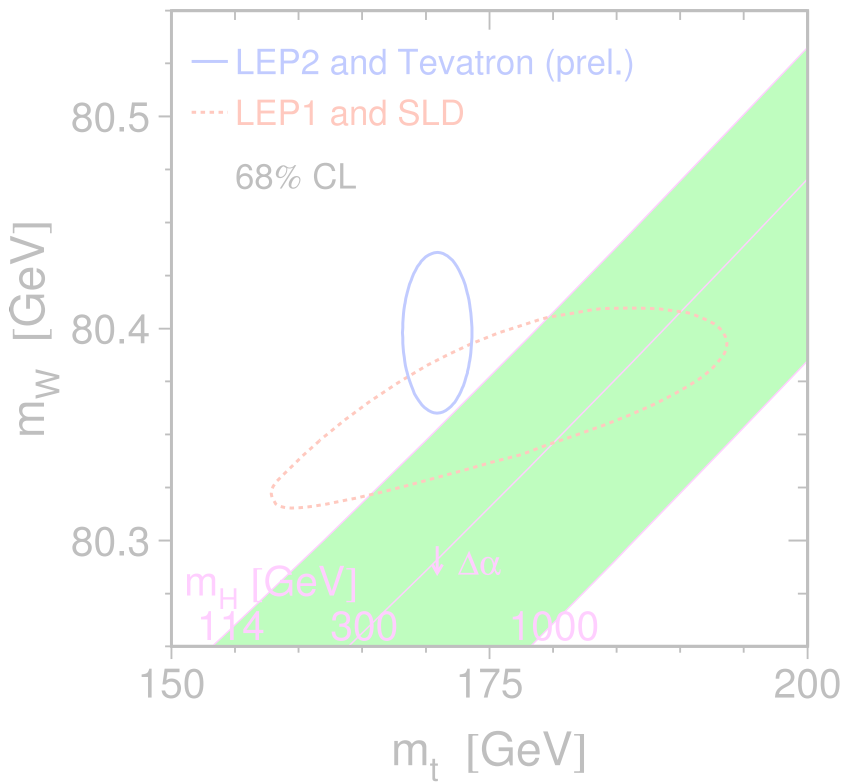


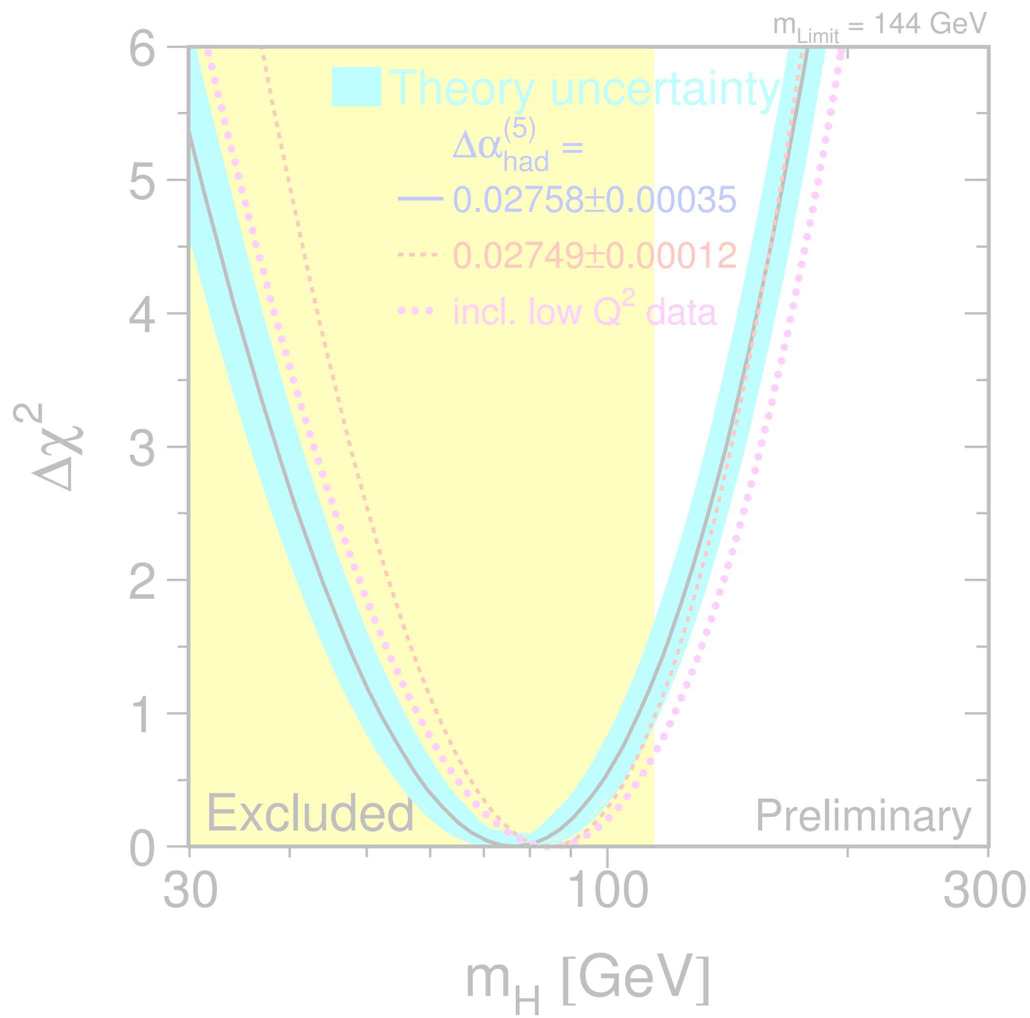
- Direct searches at LEP:
  m_H > **114.4 GeV** @ 95% CL

Constraints on the SM Higgs mass

NEW!!

- Global fit with Tevatron's
  m_{top} = **172.6 ± 1.4 GeV**
  m_W = **80.398 ± 0.025 GeV**
- m_H = **76^{+33}_{-24} GeV**
- m_H < **144 GeV** @ 95 % CL



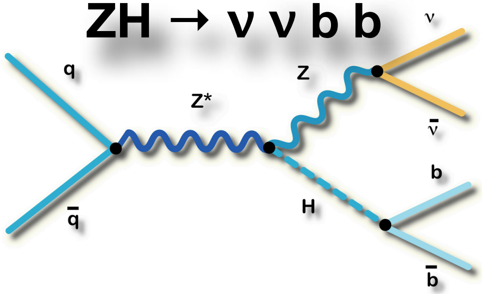


- Direct searches at LEP:
  m_H > **114.4 GeV** @ 95% CL

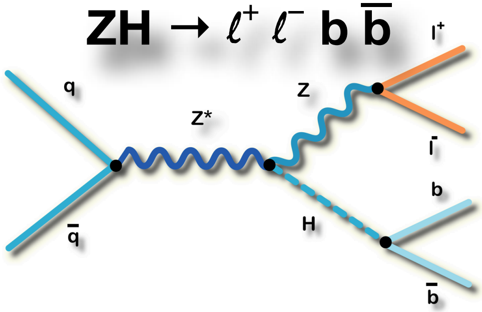
SM Higgs cross section

- Cross sections in **pb**

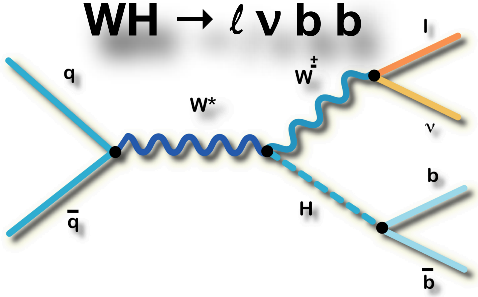
$ZH \rightarrow \nu \bar{\nu} b \bar{b}$

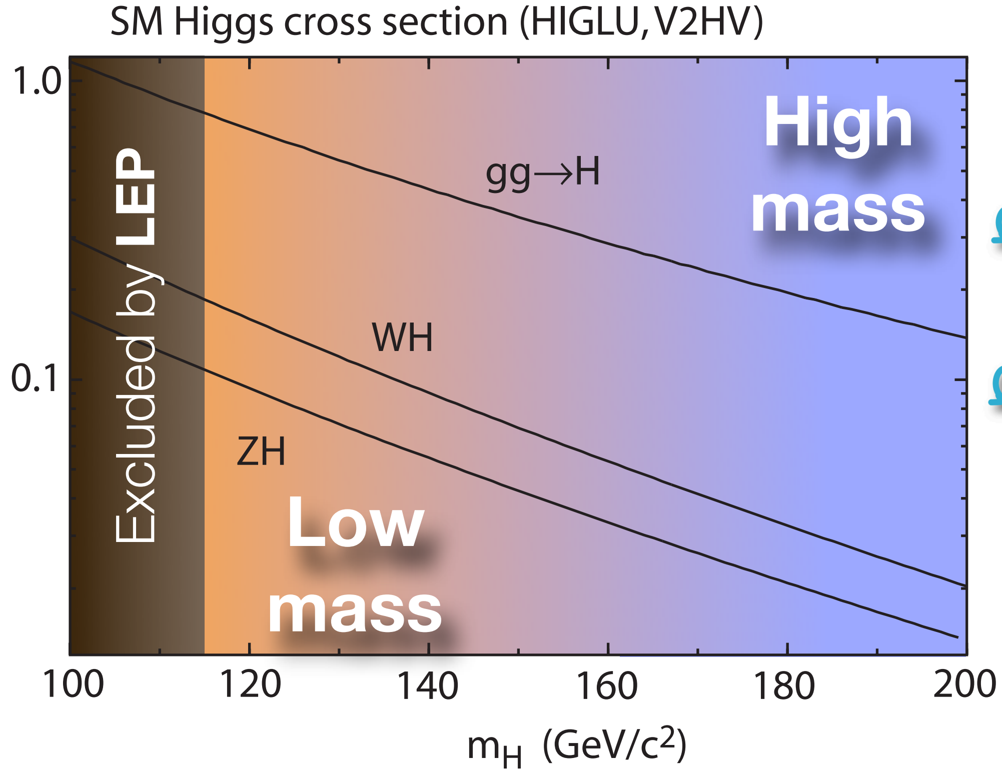


$ZH \rightarrow \ell^+ \ell^- b \bar{b}$

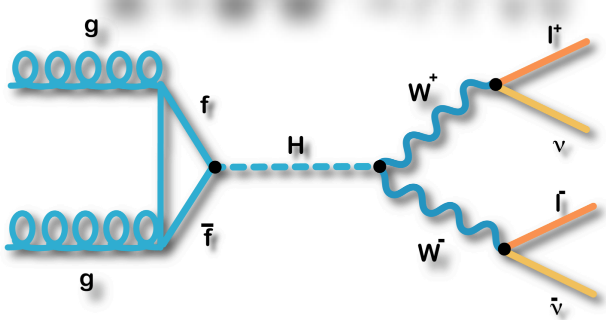


$WH \rightarrow \ell \nu b \bar{b}$



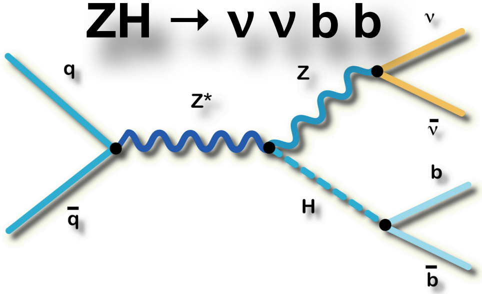


$H \rightarrow W^+W^- \rightarrow \ell^+ \ell^- \nu \bar{\nu}$

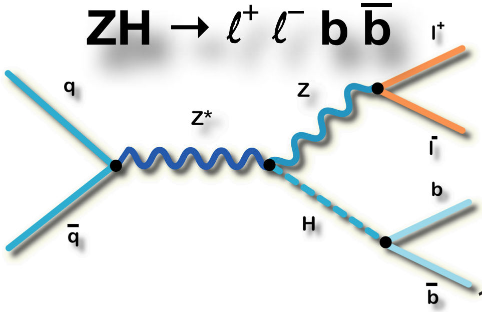


SM Higgs branching ratios

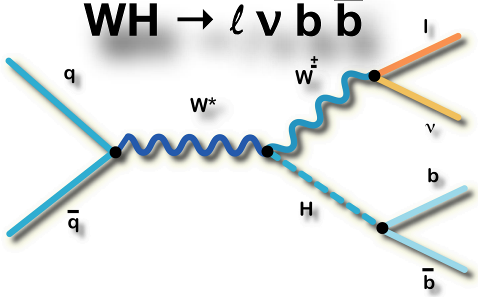
$ZH \rightarrow \nu \bar{\nu} b \bar{b}$

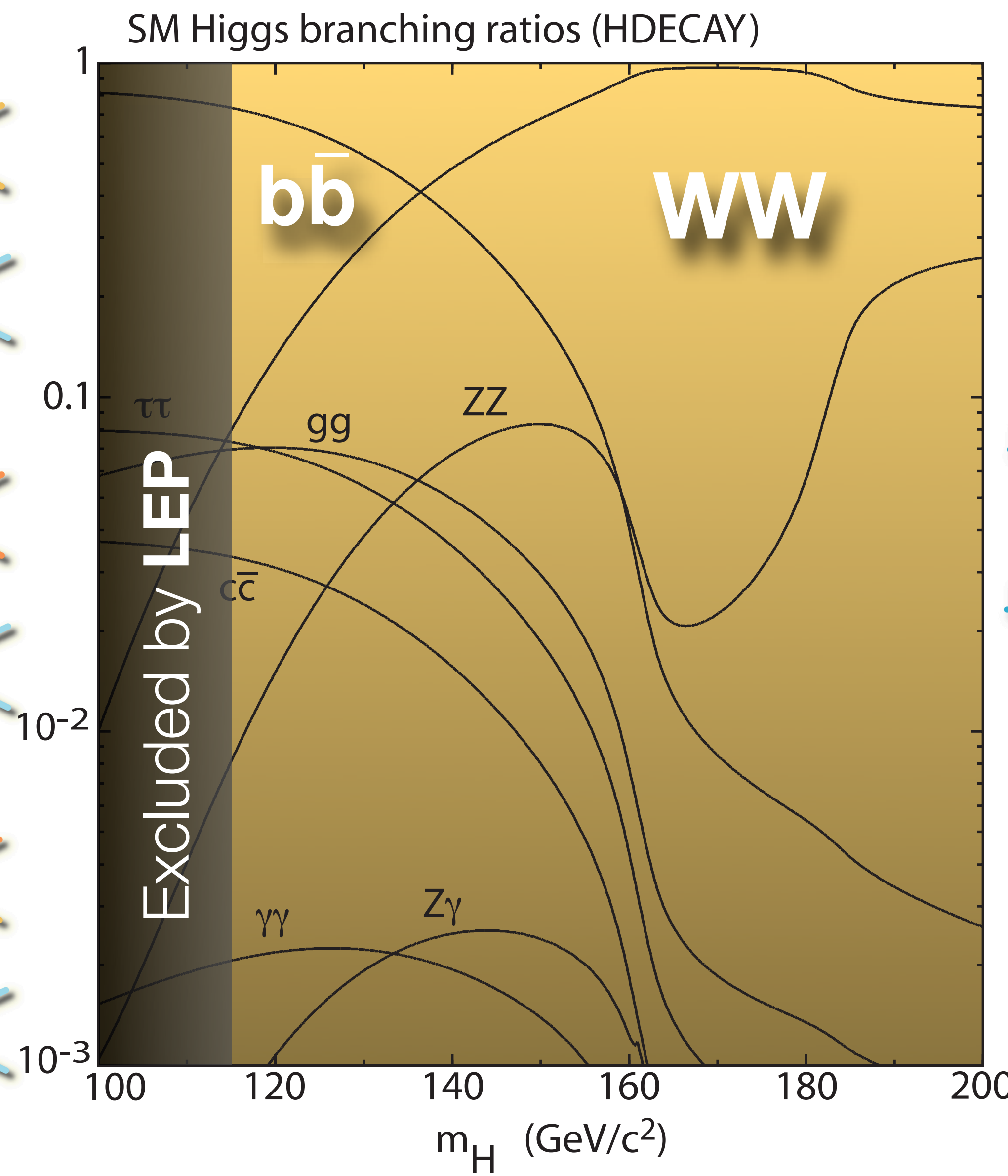


$ZH \rightarrow \ell^+ \ell^- b \bar{b}$

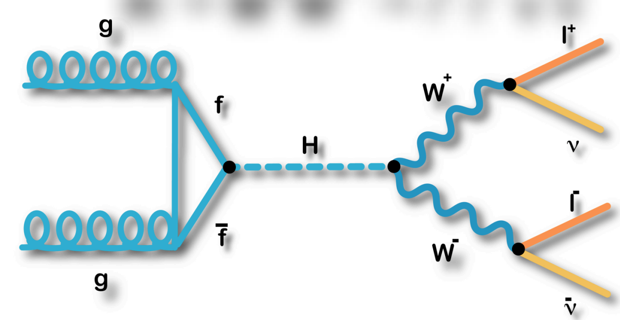


$WH \rightarrow \ell \nu b \bar{b}$



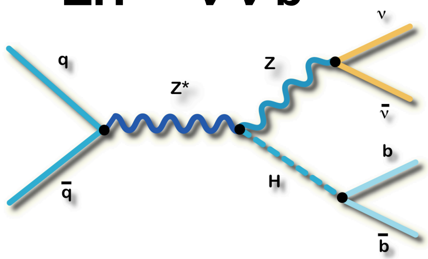


$H \rightarrow W^+W^- \rightarrow \ell^+ \ell^- \nu \bar{\nu}$

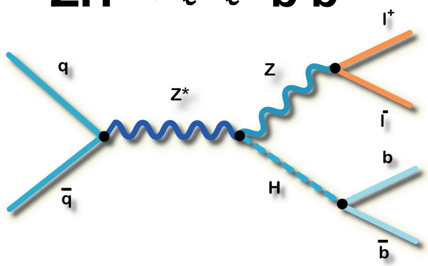


SM Higgs Tevatron limits... as of today

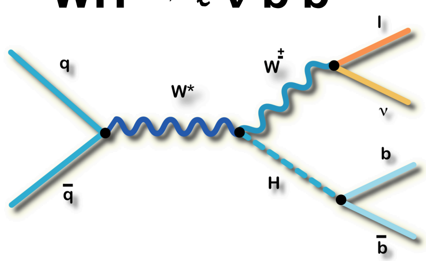
$ZH \to \nu \bar{\nu} b$



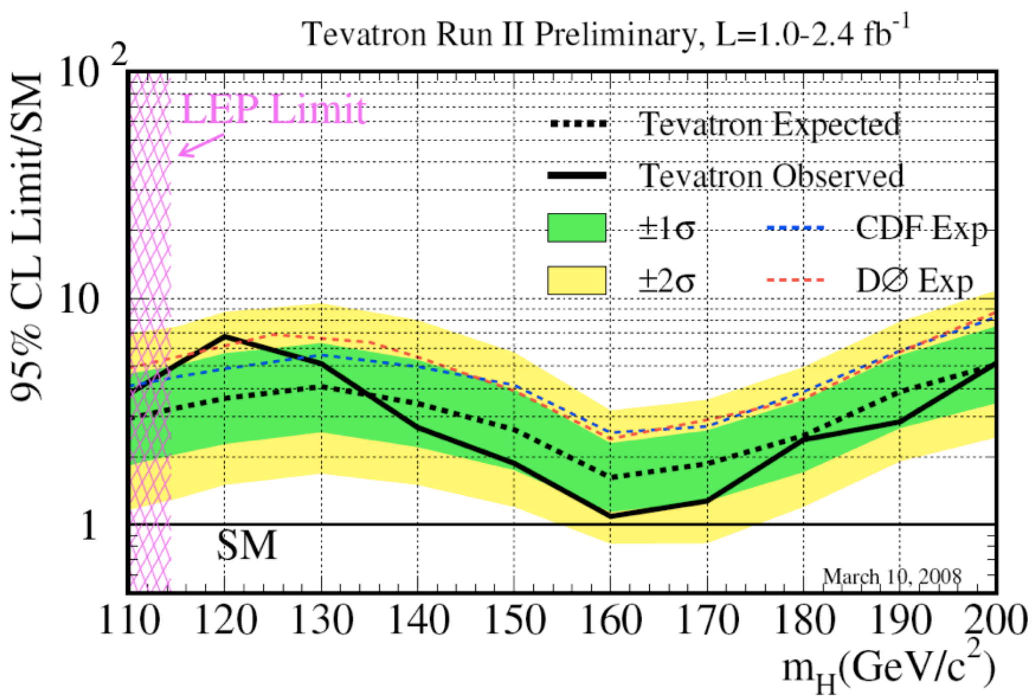
$ZH \to \ell^+ \ell^- b \bar{b}$



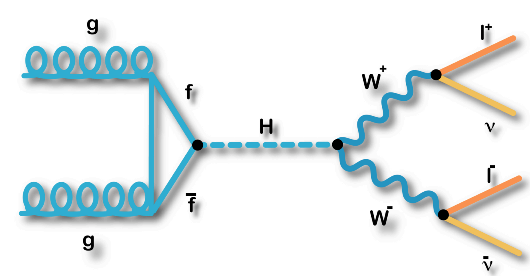
$WH \to \ell \nu b \bar{b}$



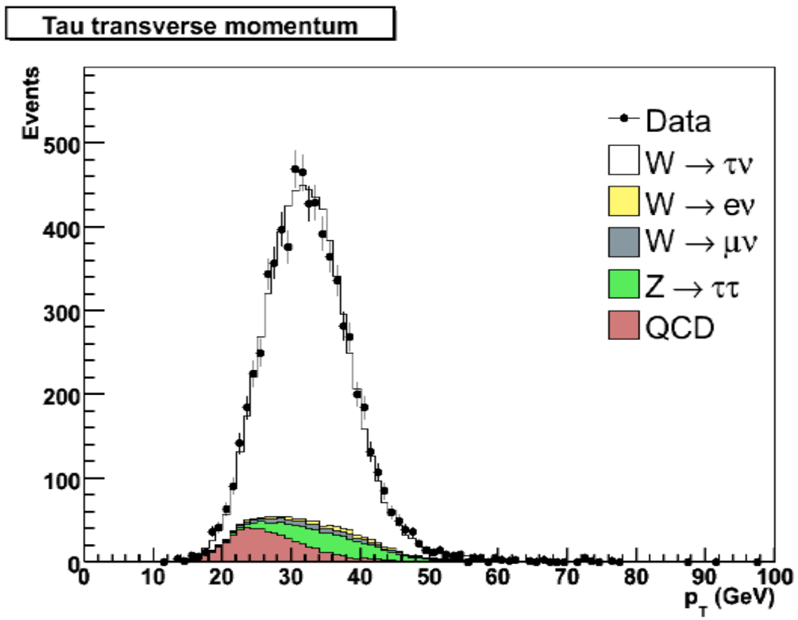
- Combined **95% CL exclusion** limits: D∅ + CDF (03/10/08)
- **All available channels** included:
  - b-pair decays at low mass → associated production W, Z
  - WW decay channel at high mass → direct production
- **Sensitivity approaching the SM** expected cross section

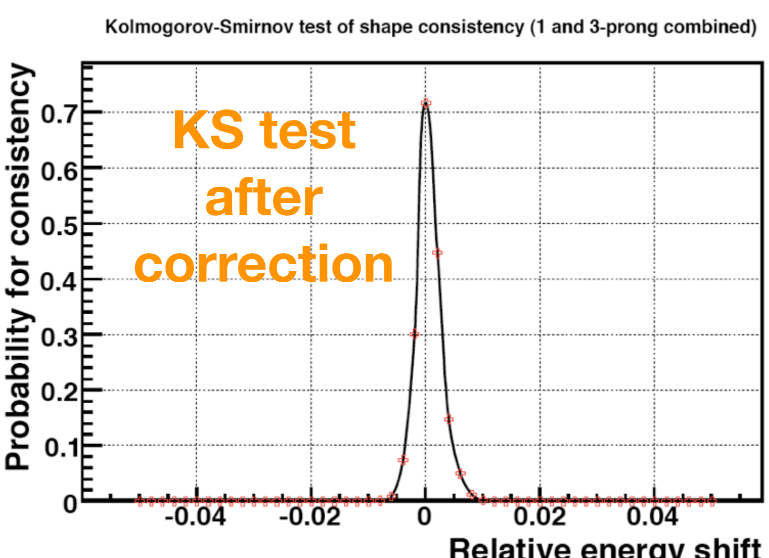


$H \to W^+W^- \to \ell^+ \ell^- \nu \bar{\nu}$



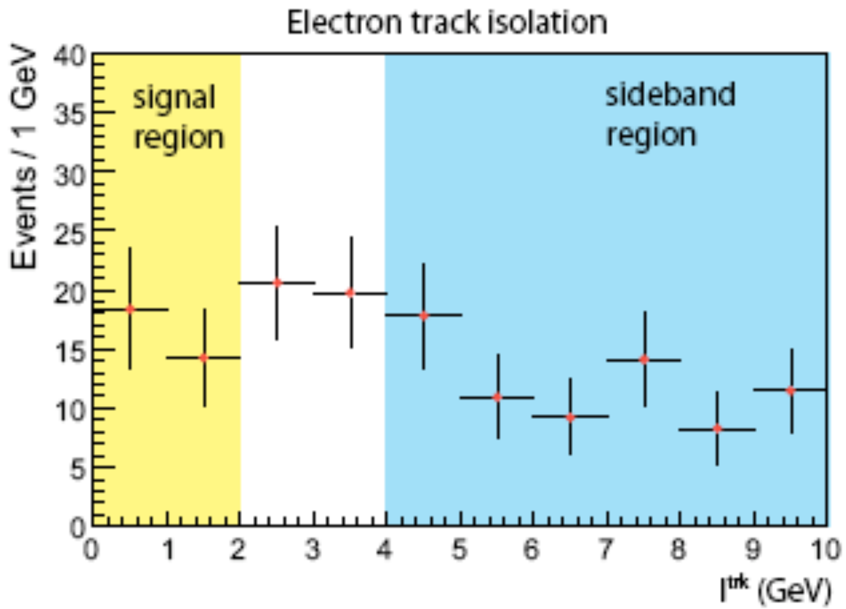
Tau energy scale

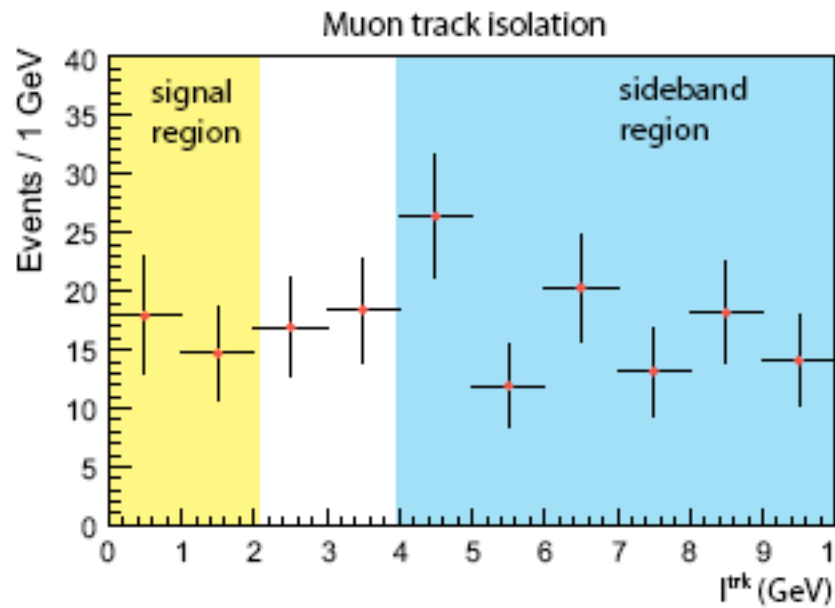




- **Clean sample** of taus used (taumet trigger sample)
- **Large missing E_T**, $\not{E}_T$, veto events with any additional jet activity
- Very tight selection of $W \to \tau\upsilon_\tau$
- Tau p_T distribution in data compared to **shifted distributions** in MC, with a KS test
- **Tau energy scale** in data/MC is compatible to 1%

Lepton sidebands

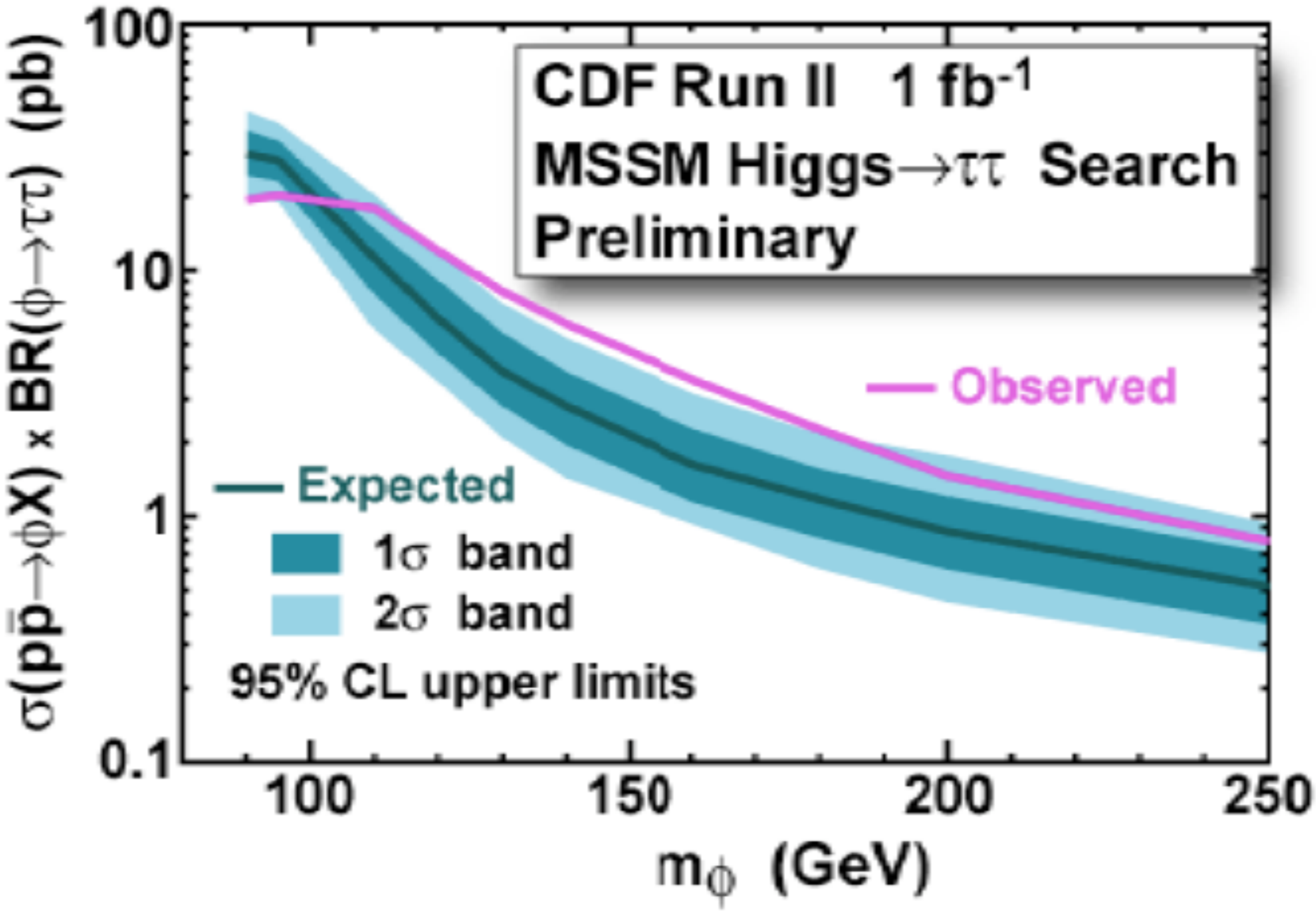




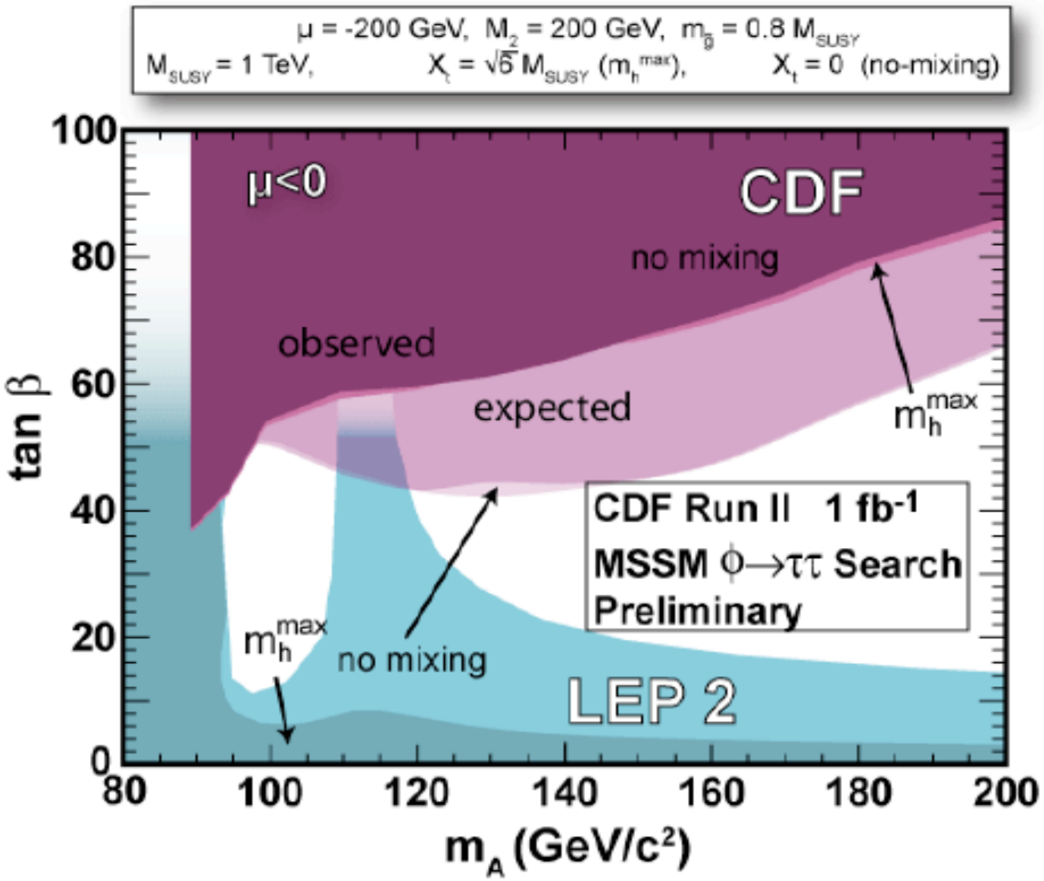
- Either **jets faking leptons** OR leptons in jets
- Select dilepton events:
  - one tight
  - investigate **isolation sidebands** for the other lepton

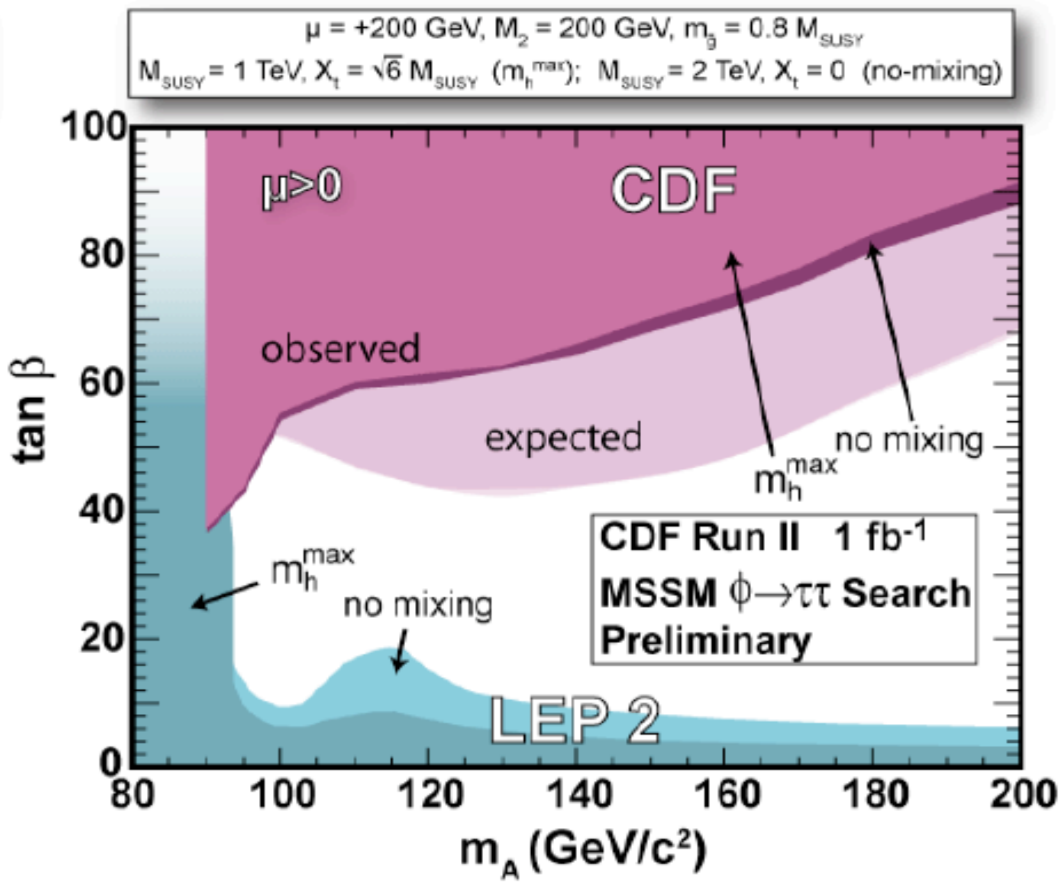
- Distribution could not be flat
- **Same sign** events used as a control region
- A scale factor of 1.15 is needed, with an systematic error associated to the method of a 20%

95% CL exclusion limit on σ x BR, 1 fb^{-1}

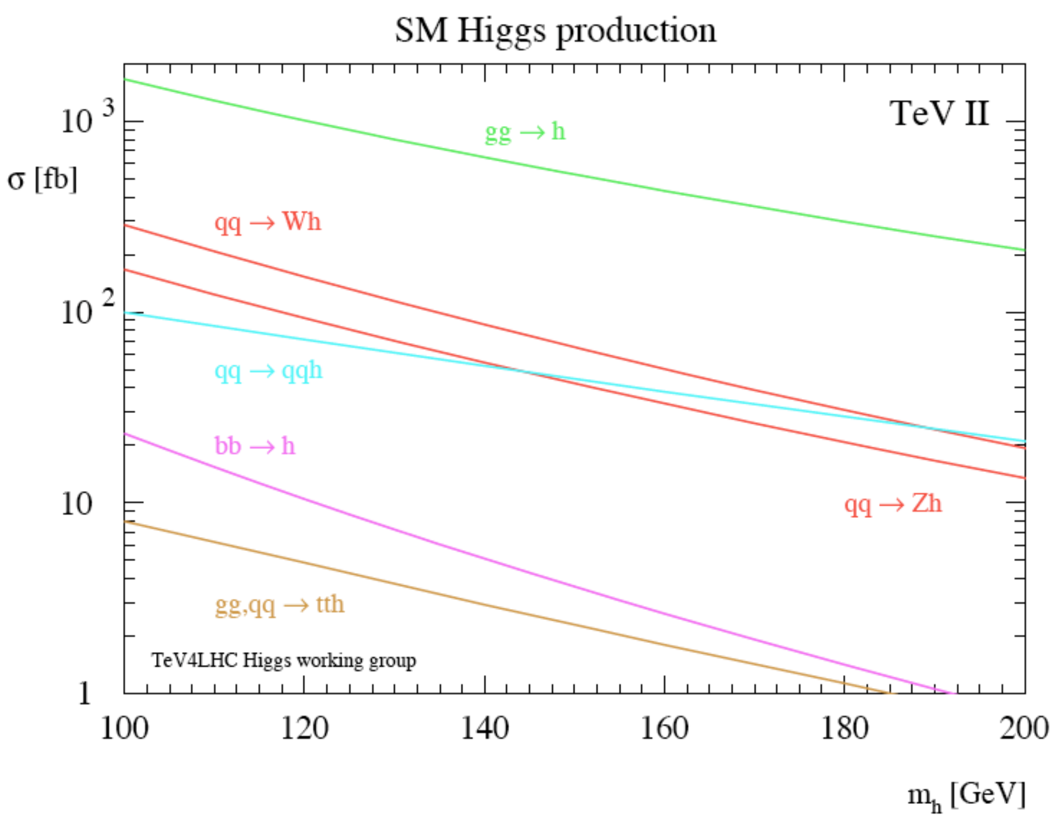


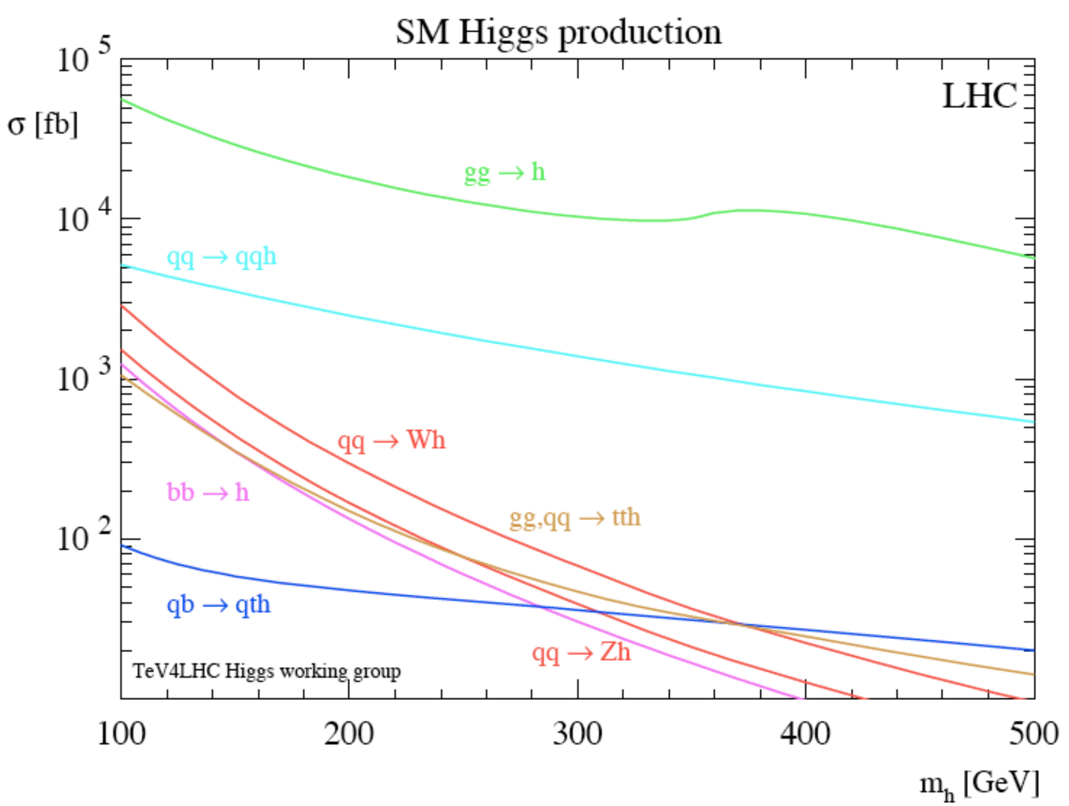
Limits in m_A *vs* $\tan\beta$, 1 fb^{-1}



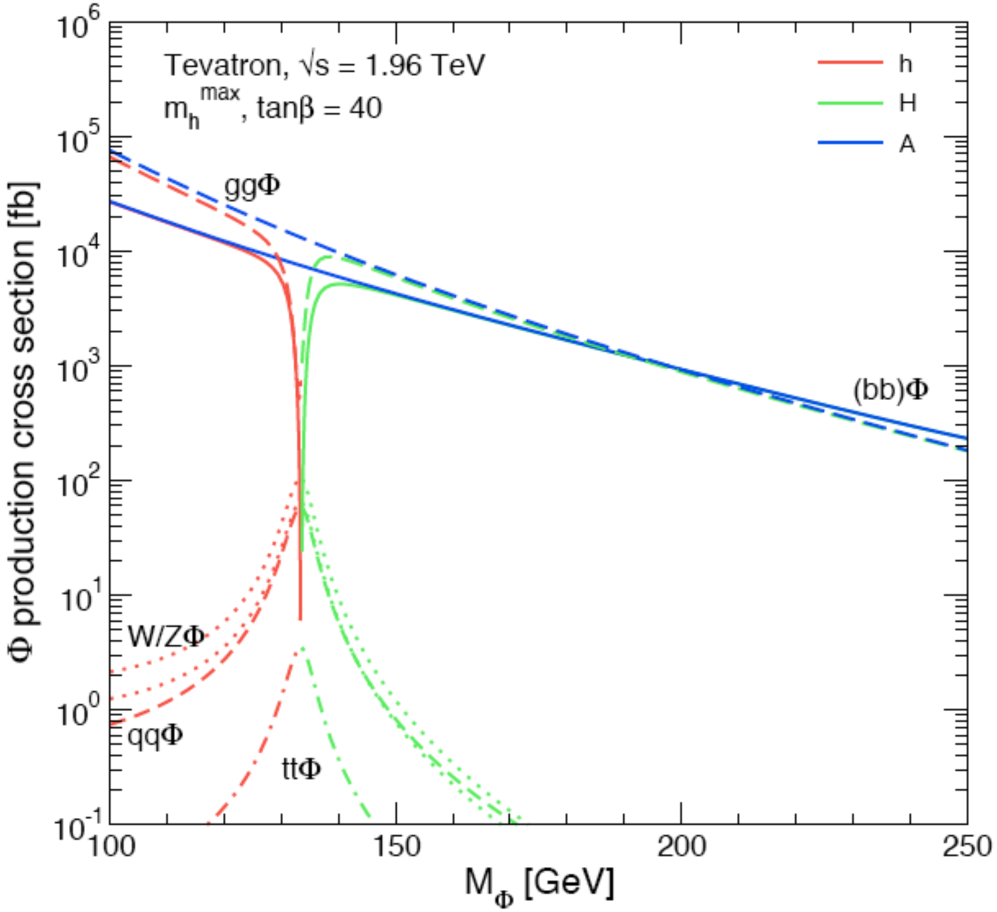


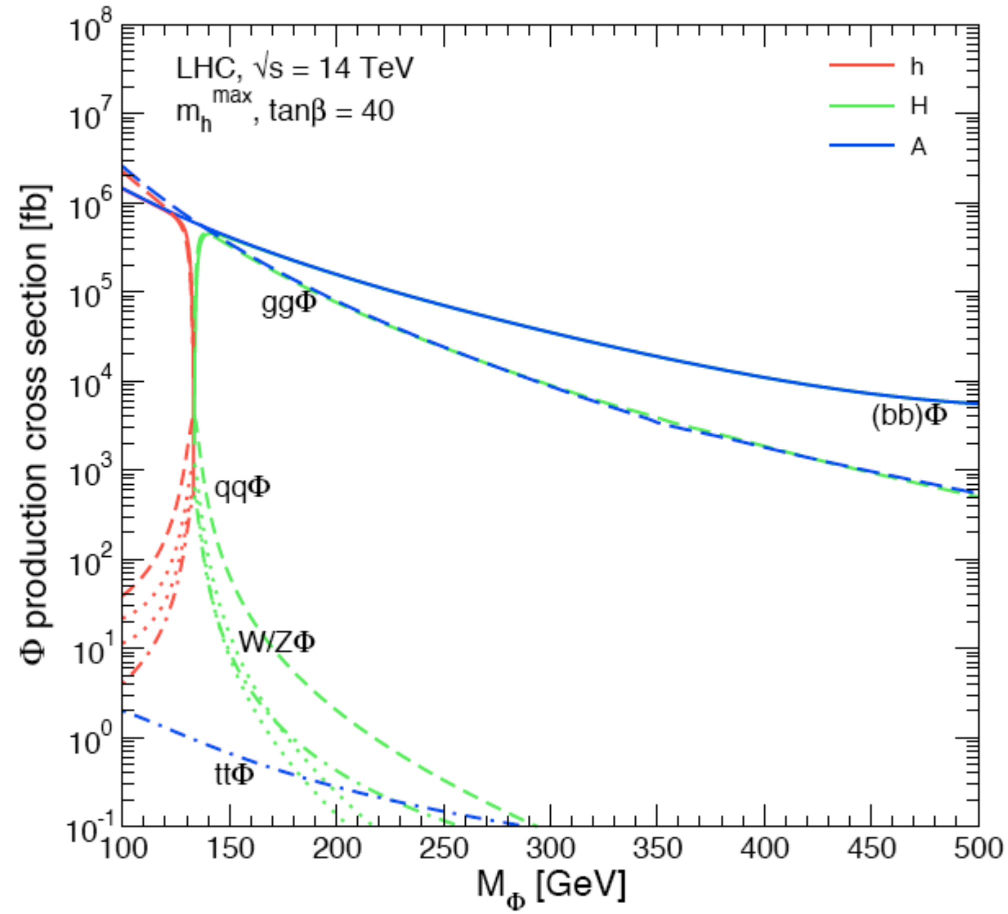
SM Higgs cross section: TeV to LHC





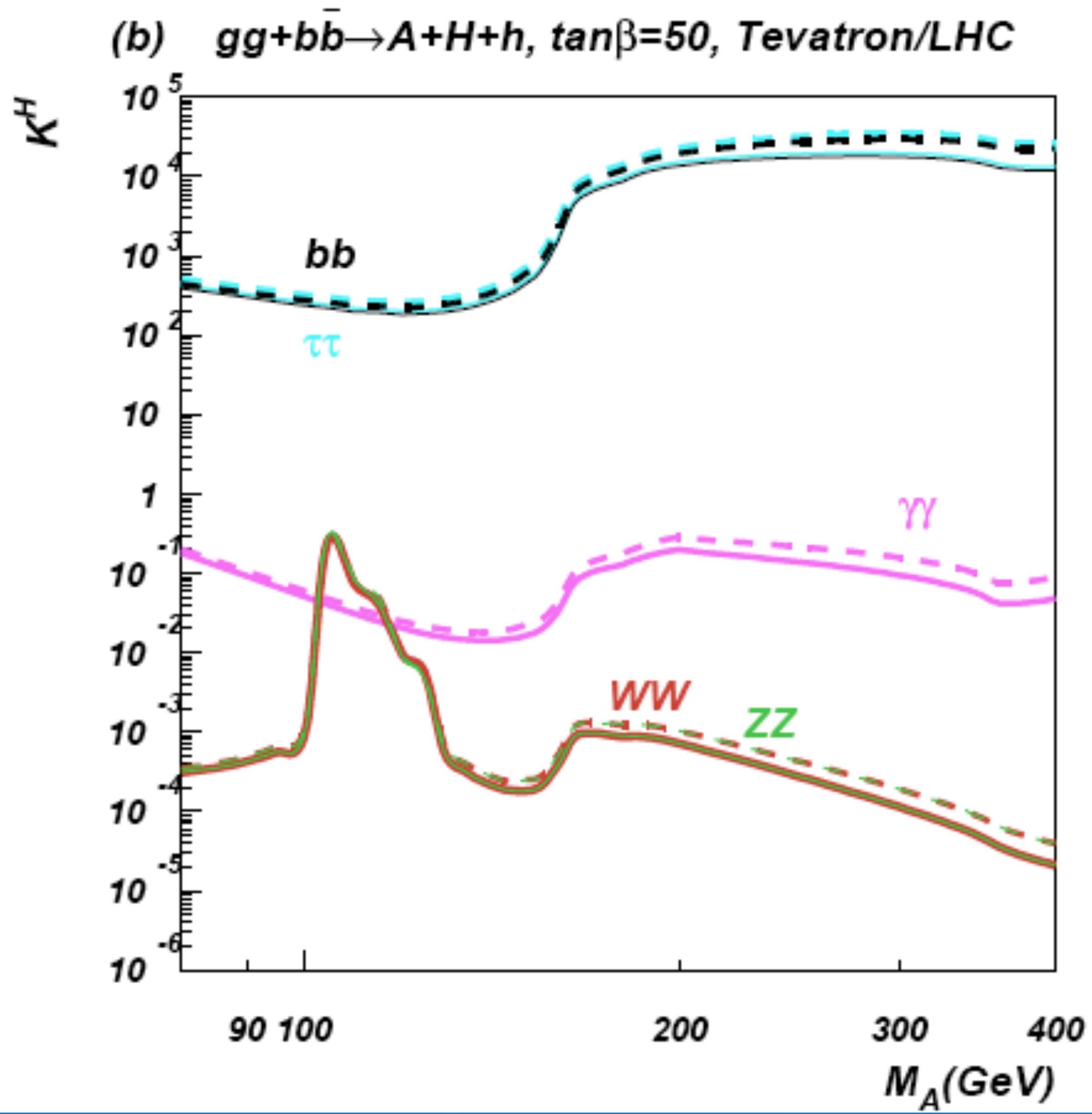
MSSM Higgs cross section: TeV to LHC



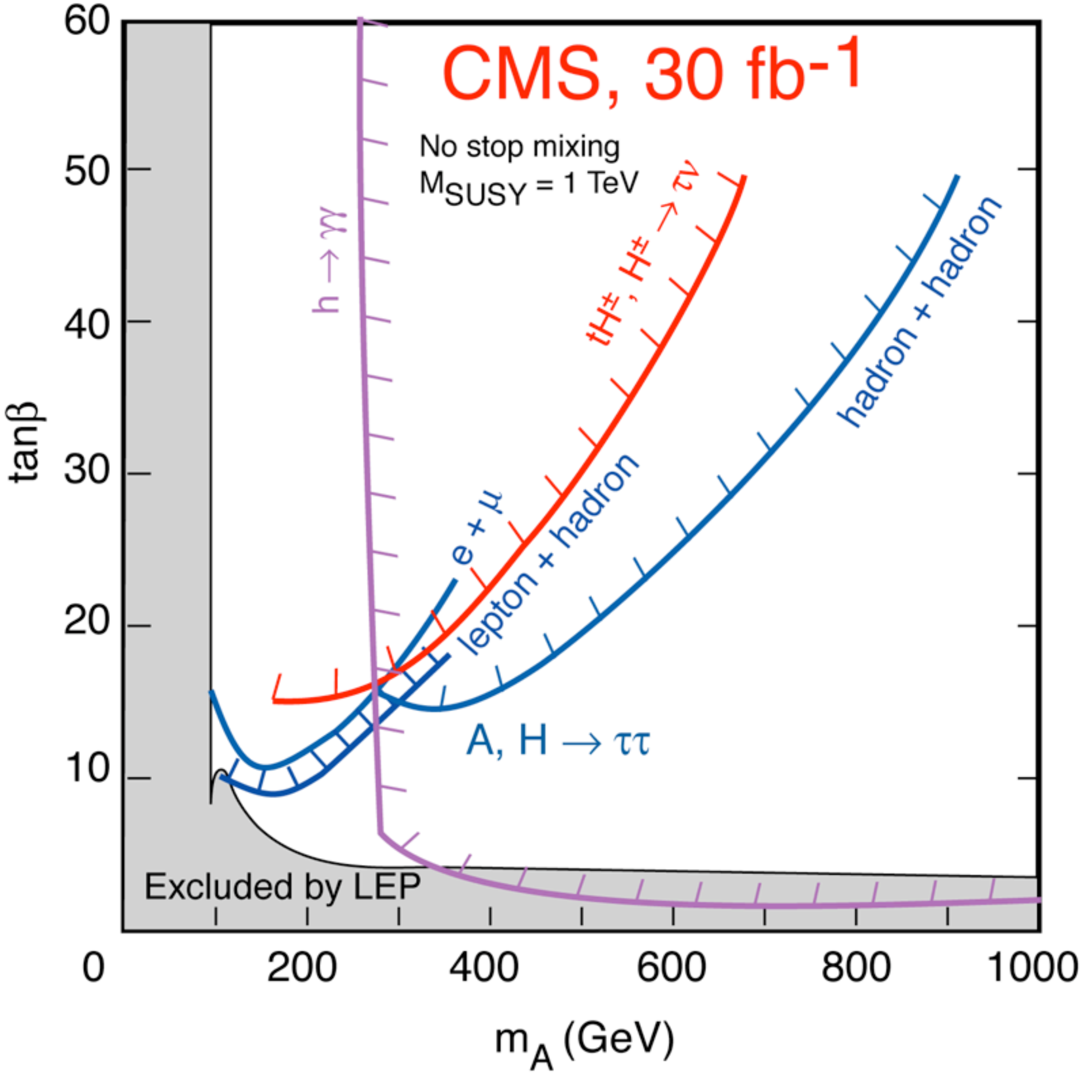


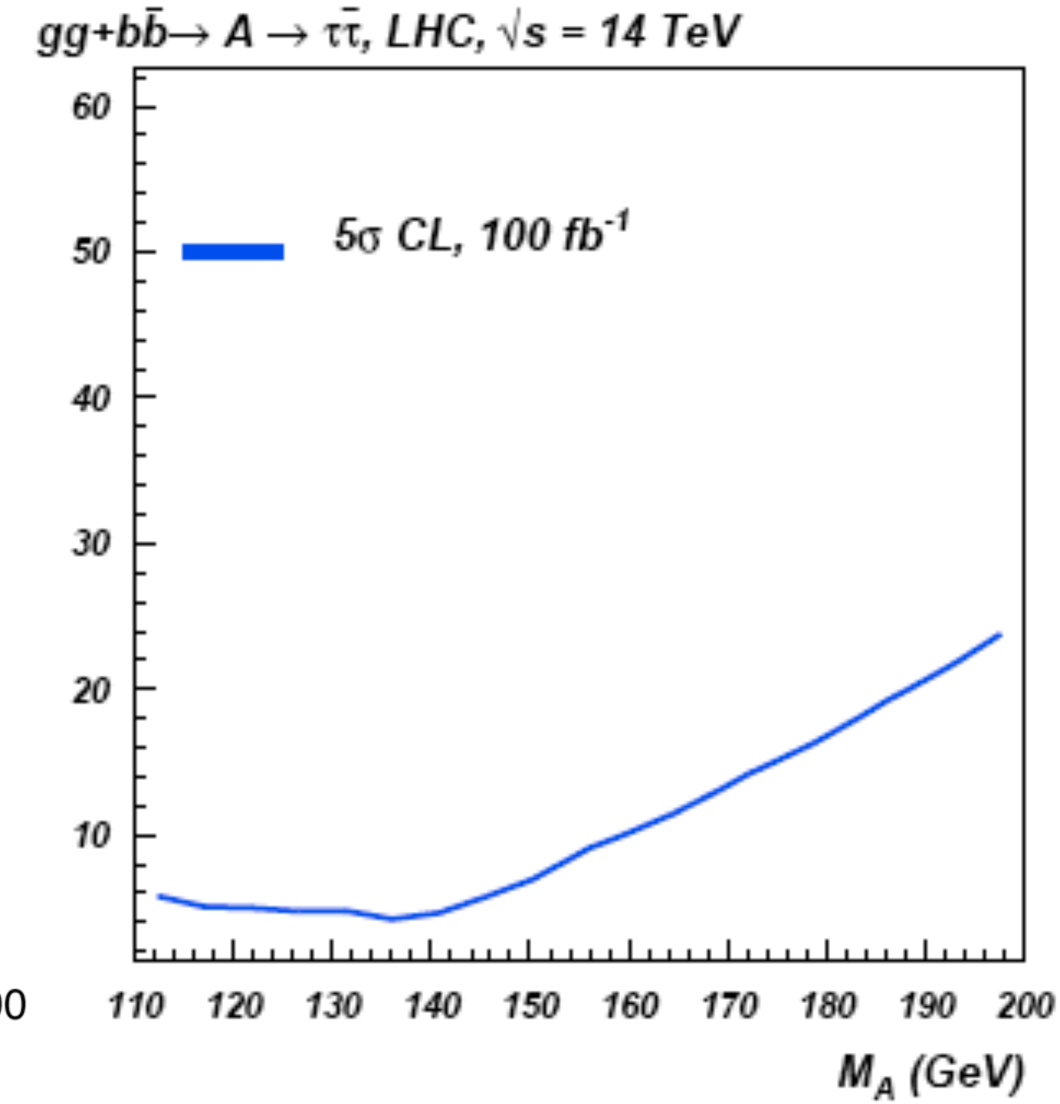
MSSM Higgs: Xsec enhancement factors

- Solid line:
  Tevatron
- Dashed line:
  LHC



MSSM Higgs: expected sensitivity LHC





MSSM scenarios

$m_h^{\max}$:

$$m_t = 174.3\text{ GeV},\ M_{\text{SUSY}} = 1000\text{ GeV},\ \mu = 200\text{ GeV},\ M_2 = 200\text{ GeV},$$
$$X_t^{\text{OS}} = 2\,M_{\text{SUSY}}\ \text{(FD calculation)},\ X_t^{\overline{\text{MS}}} = \sqrt{6}\,M_{\text{SUSY}}\ \text{(RG calculation)}$$
$$A_b = A_t,\ m_{\tilde{g}} = 0.8\,M_{\text{SUSY}}\ .$$

no-mixing:

$$m_t = 174.3\text{ GeV},\ M_{\text{SUSY}} = 2000\text{ GeV},\ \mu = 200\text{ GeV},\ M_2 = 200\text{ GeV},$$
$$X_t = 0\ \text{(FD/RG calculation)}\ A_b = A_t,\ m_{\tilde{g}} = 0.8\,M_{\text{SUSY}}\ .$$

```
! Snowmass E3 (LC) group MSSM
! benchmark parameter set 2 (heavy
! sparticles)
!
IMSS(1)=1
IMSS(3)=1
IMSS(4)=1
IMSS(8)=0
RMSS(1)=  121.92
RMSS(2)=  234.80
RMSS(3)=  778.59
RMSS(4)=  222.29
RMSS(6)=  1456.38
RMSS(7)=  1451.73
RMSS(8)=  1532.73
RMSS(9)=  1529.60
RMSS(10)=  1288.4
RMSS(11)=  1516.84
RMSS(12)=  985.66
RMSS(13)=  1449.62
RMSS(14)=  1438.94
RMSS(15)= -787.52
RMSS(16)= -551.94
RMSS(17)= -184.74
RMSS(22)=  1529.60
! tan beta
RMSS(5)=  50.00
! m(A)
RMSS(19)=  190.0
```