Tau Physics at CDF

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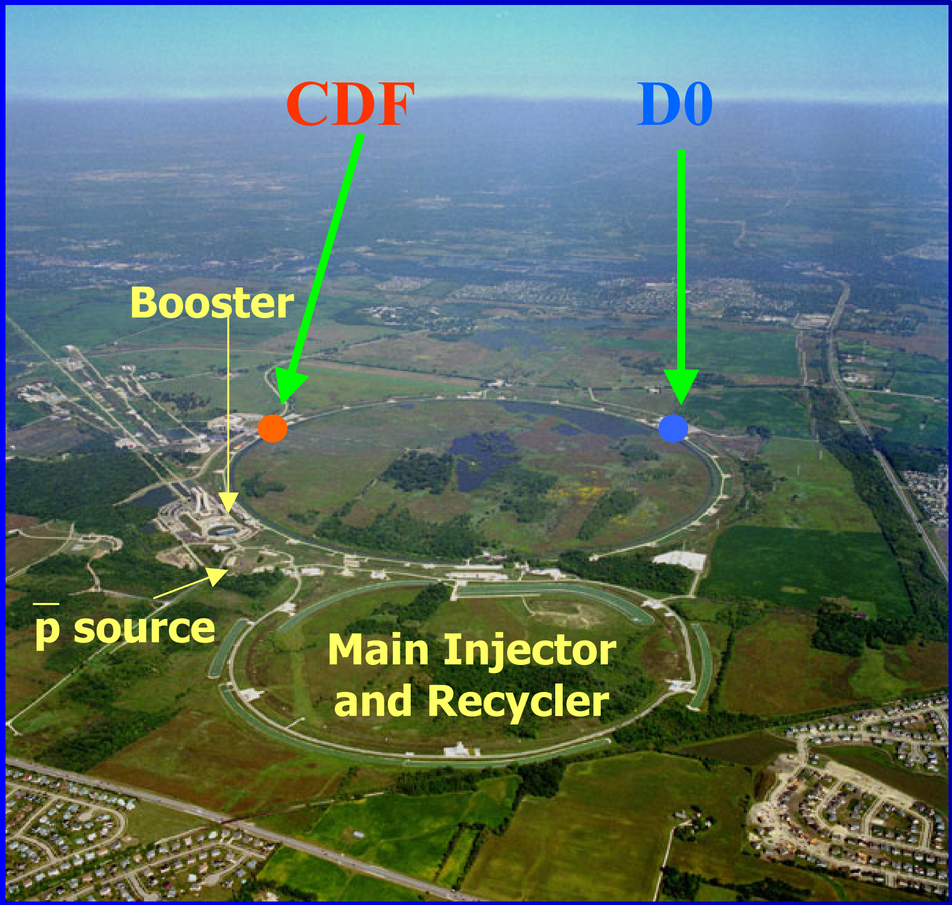
Outline

- Tau Physics at Hadron Colliders
- Tau Detection at CDF:
  - Reconstruction
  - Tau Triggers
  - Identification
- Backgrounds
- CDF-II First Physics Results:
  - Electroweak
  - Higgs and Exotics Searches
- Summary

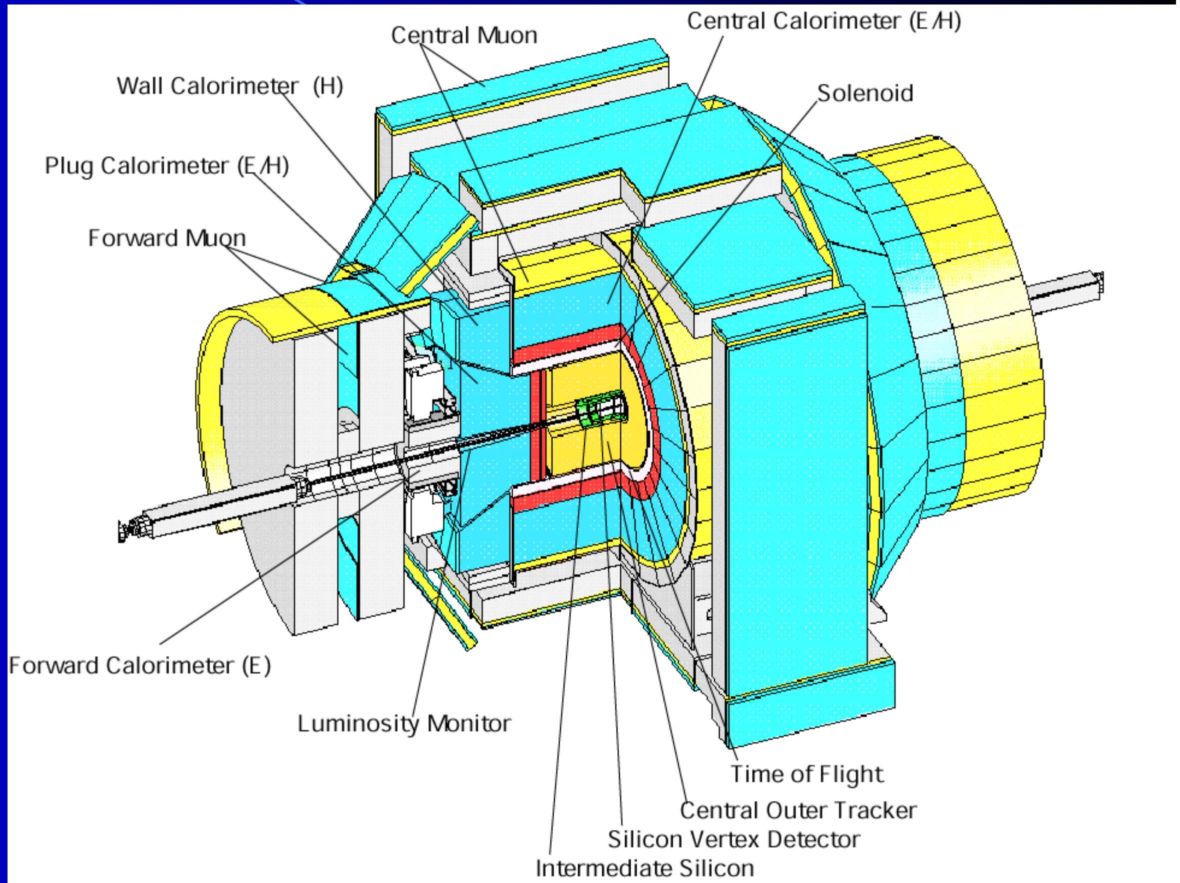
Fermilab Tevatron



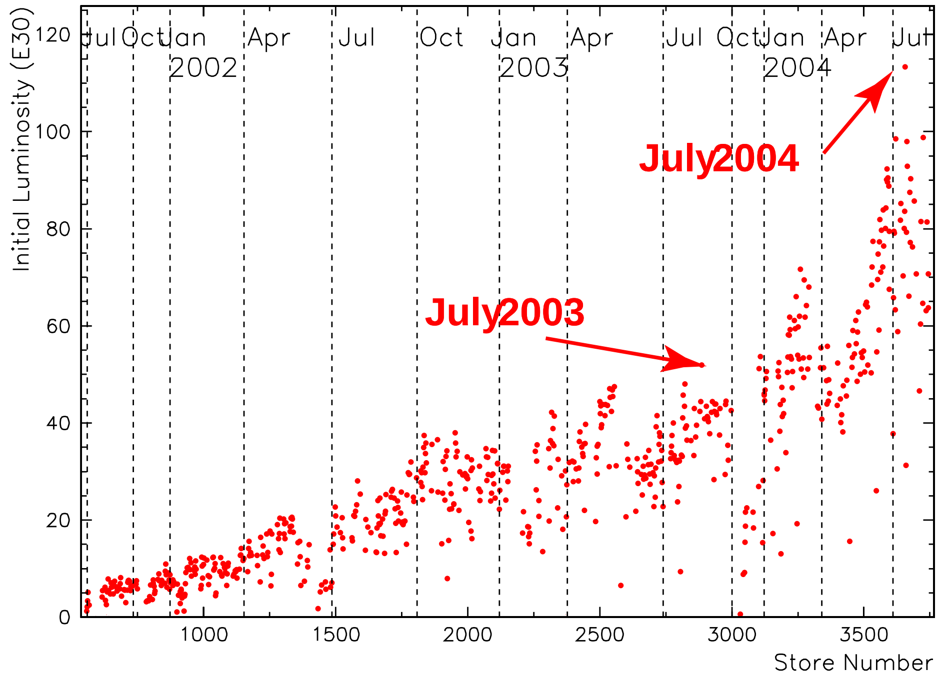
- Major Upgrade for Run II:
  - Beam E=980 GeV
  - Collisions every 396 ns
  - Instantaneous Lumi ~ (few x $10^{32)}$ $cm^{-2}s^{-1}$
  - 2-3 interactions per bunch crossing
  - Expected Integrated L ~ 4-8 fb^{-1} (by 2009)

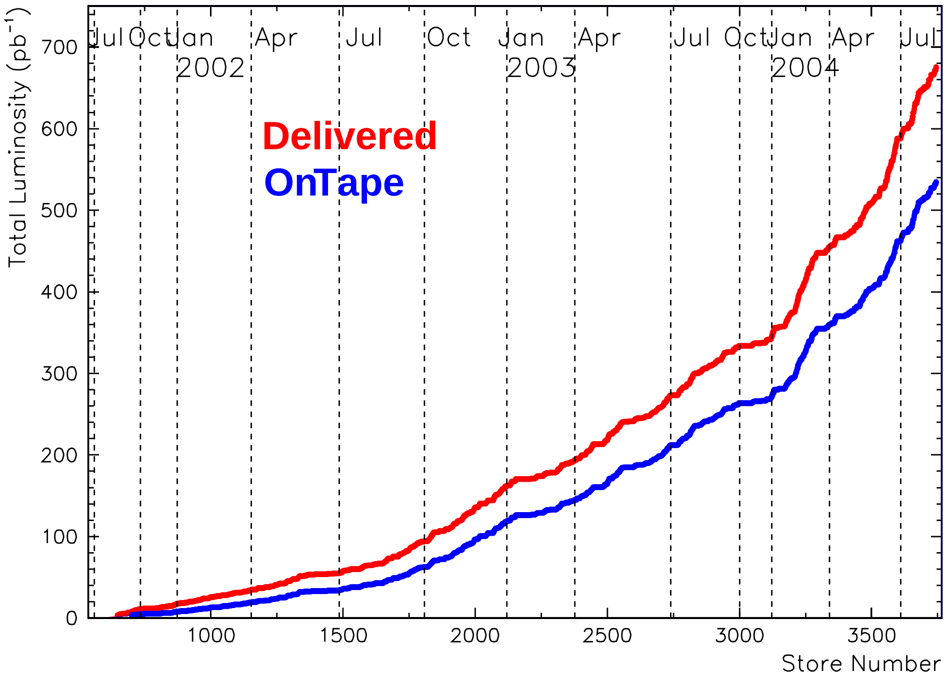
CDF Detector

- Many Improvements compared to Run I:
  - New DAQ
  - New Track Trigger
  - New Silicon $|\eta|<2$
  - Improved b-tagging
  - New Drift Chamber
  - New Plug Calorimeter
  - Increased acceptance
  - Upgrade Muon Detectors



Data and Luminosity

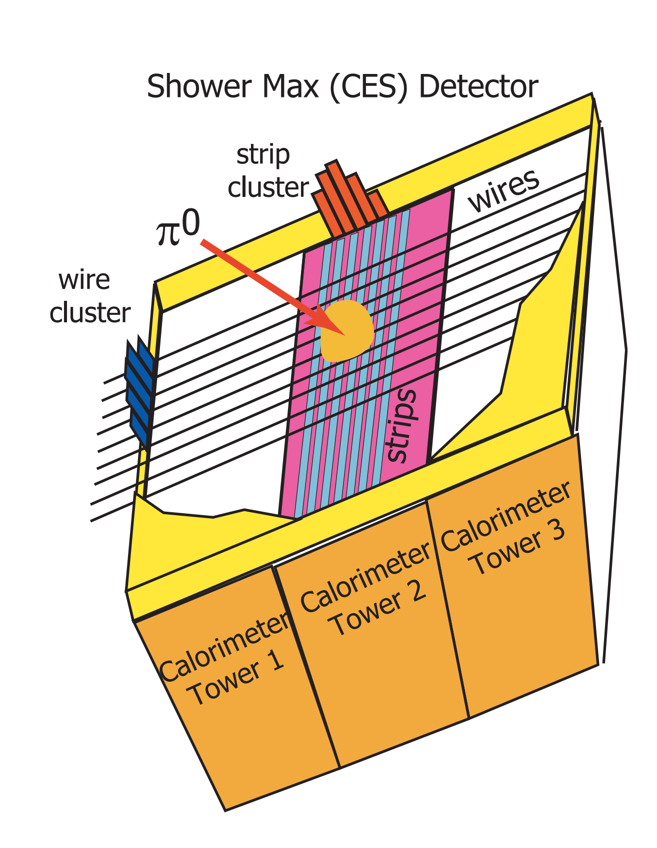




- CDF:
  - about 500 pb-1 on tape
    - over 400pb-1 of high quality data (Winter 2005 analyses)
  - Average Data Taking Efficiency is about 80%
  - Record Instantaneous Luminosity 1.13 x 10^{32}

CDF Detector and Taus

- Tracks:
  - Central Tracker + Silicon Vertex Detector
  - Good tracking (efficiency in high 90's, $|\eta|<1$)
- Calorimeter clusters:
  - Segmentation ($\Delta\eta=0.1$) x ($\Delta\phi=15^0$)
    - Compare to typical tau size of ~5-10^0
    - Poor resolution for hadronic part
- Pions:
  - ShowerMax (CES) Detector
    - strip/wire chamber inside EM calorimeter
    - Spatial resolution ~few mm
  - Reconstruct π^0s as 2D matches in CES
  - Assign energy from EM calorimeter



Tau Reconstruction

- CDF Tau Object = tracks + π^0s + calorimeter towers
- Tau Candidate Reconstruction:
  - Start with a seed calorimeter tower E_T>6 GeV (being lowered to 4 GeV)
  - Clustering algorithm combines nearby towers with E_T>1 GeV
  - Only clusters with 6 or less towers retained
  - A seed track with P_T>5 GeV pointing to the cluster
  - Reconstructed tracks and p0's are added

Reconstruction Efficiency:

~70% at 15 GeV

~85% at 25 GeV

~95% at 40 GeV

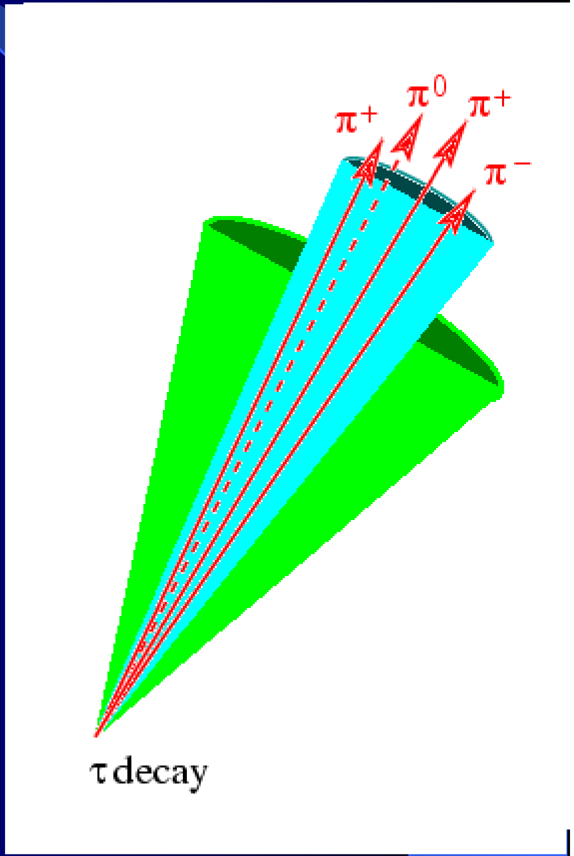
Tau ID

- Tracks and π^0s within the signal cone (10^0 for soft taus) are associated with the tau:
  – Momentum: $\vec{p}^{\tau} = \sum \vec{p}^{trk} + \sum \vec{p}^{\pi^0}$
  – Energy = $E^{\tau} = \sum E^{trk} + \sum E^{\pi^0}$
  – Invariant mass of 4-vector $(E, \vec{p})$
- Tracks and π^0s between 10-30^0 counted in isolation:

$$I^{trk} = \sum p_T^{trk} < I_0^{trk}$$

$$N_{p_T > 1\,GeV}^{trk/\pi^0} = 0$$

$$I^{\pi^0} = \sum p_T^{\pi^0} < I_0^{\pi^0}$$



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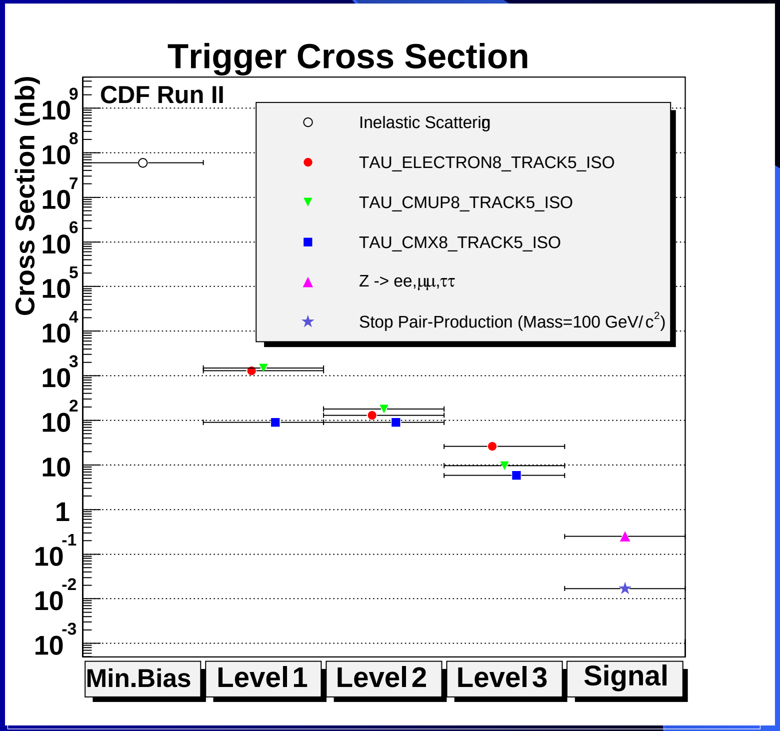
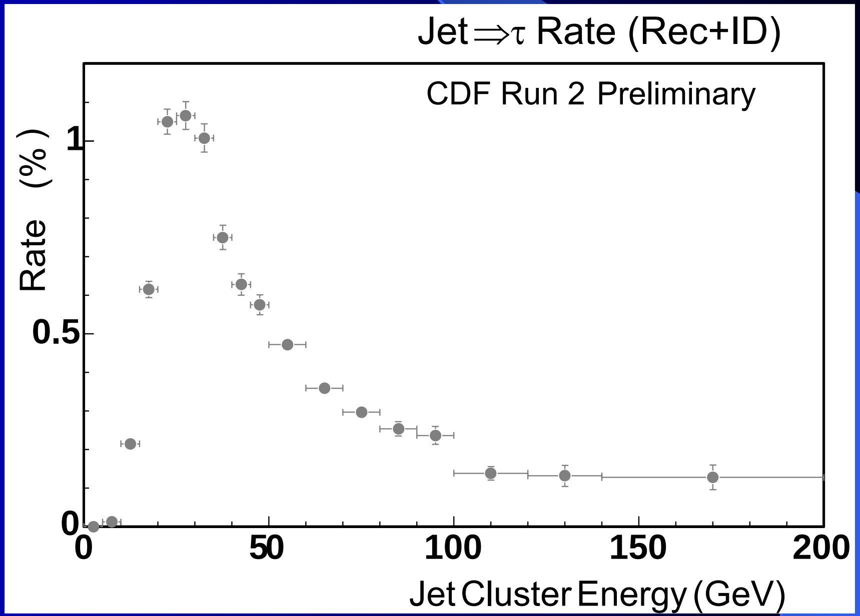
CDF Tau Triggers

- Lepton+Track Triggers:
  - Central lepton (e or μ) $p_T>8$ GeV
  - Additional isolated track (seed for τ) $p_T>5$ GeV
  - Target signature: $\tau_e+\tau_h+X$, $\tau_\mu+\tau_h+X$
- Di-Tau:
  - $E_T^{cal}>10$ GeV
  - $P_T^{seed}>10$ GeV
  - 10-30^0 2D track iso in Level 2
- Tau-MET:
  - $E_T^{cal}>20$ GeV
  - Missing $E_T>20$ GeV
  - 10-30^0 2D track iso in Level 2



Tau Backgrounds

- Backgrounds misidentified as taus:
  - QCD Jets
  - Electrons that shower late or with strong Bremstrahlung
  - Muons interacting in the calorimeter



- Typical fake rates:
  - Jets ~ 0.5-1%
  - Electrons $\sim 10^{-3}$
  - Muons $\sim 10^{-4}$
  - Plots shows fake rate as a function of calorimeter cluster energy for taus with $P_T(\text{tracks}+\pi^0\text{s})>25$ GeV
    - Note that the two are correlated

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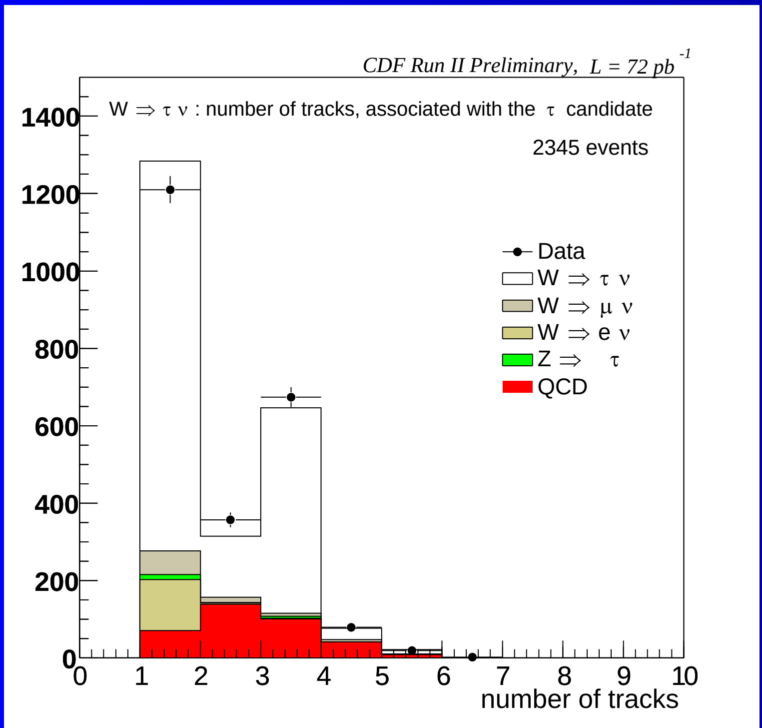
Electroweak: $W \rightarrow \tau\nu$

- By far the largest and cleanest source of taus at the Tevatron
- First CDF analysis exploring taus
- Goal: g_τ/g_e - test of lepton universality



- Tau: P_T(tracks+π^0s)>25 GeV
- MET>25 GeV
- Events with extra jets ET>5 GeV $|\eta|$<2.4 are vetoed
- Good agreement with the MC expectation

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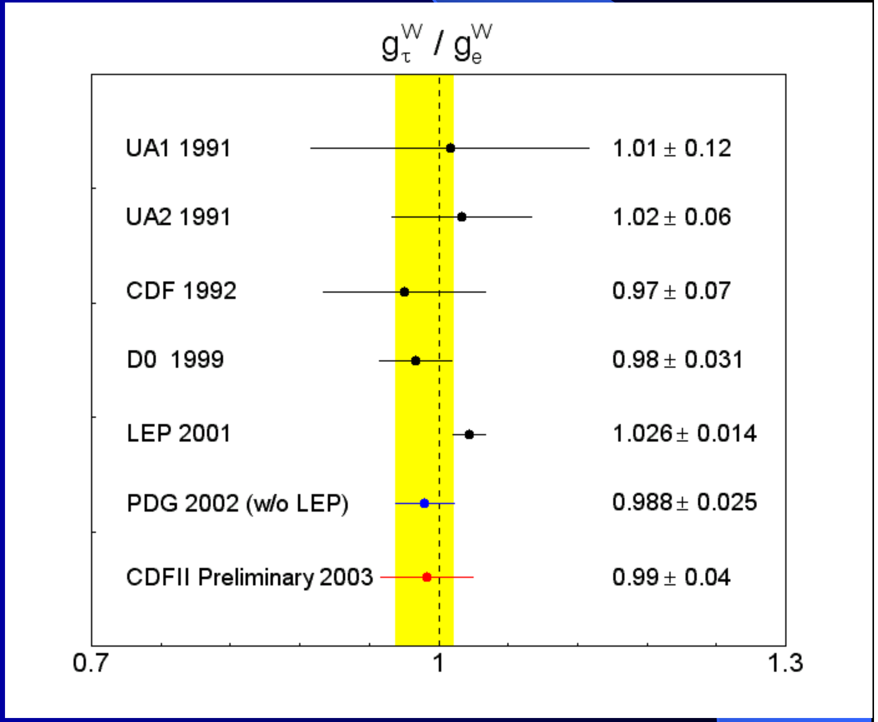
Electroweak: W→τν

- Lepton Universality:
  - Extract g_τ/g_e from the ratio of W→τν and W→eν cross-sections
  - Many systematic uncertainties cancel out
  - Significant improvement over Run I
  - Will improve with more statistics

$$\frac{g_\tau}{g_e} = 0.99 \pm 0.04$$



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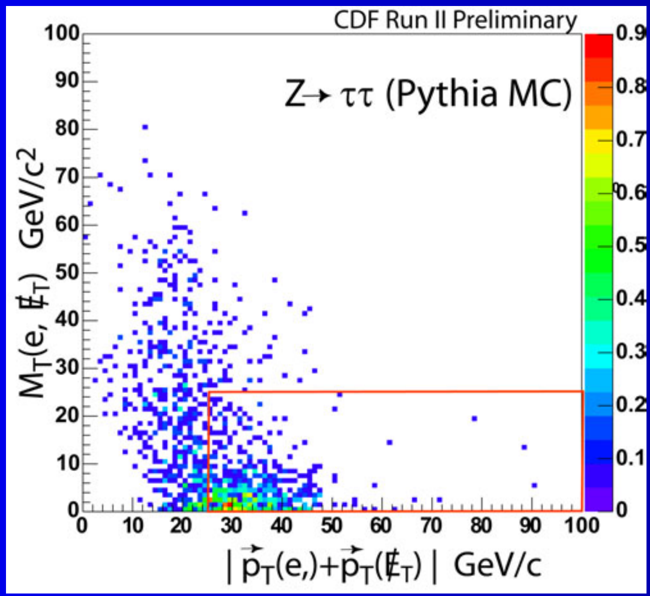
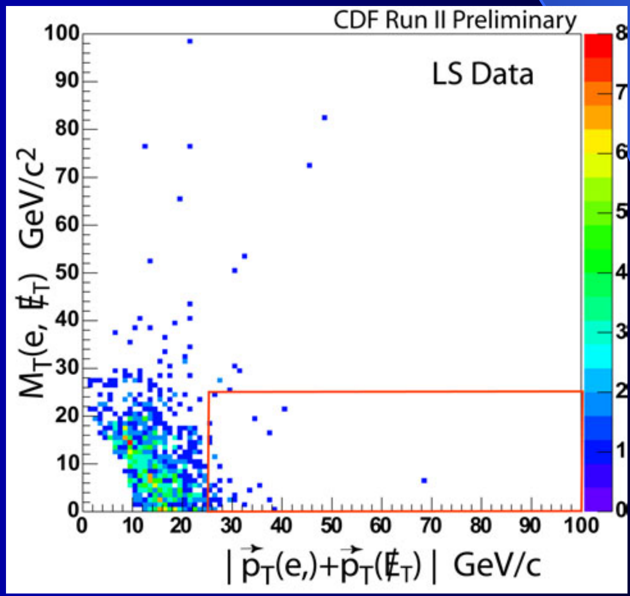
Electroweak: $Z \to \tau\tau$

- Why bother?
  - Cross-section: never measured at Tevatron
  - Largest irreducible background to most of the searches
  - Testing ground for estimating other backgrounds and tuning efficiencies
    - Low systematics means better reach for new physics

Selection and Efficiencies

Acceptance	Tau: P_T>15 GeV Ele: E_T>10 GeV Both in central fiducial region	**5.48±1.1(stat)±1.5(syst)%**
Ele ID Cuts	Standard CDF ID, Track Isolation	**72.1±1.0(stat)±3.1(syst)%**
Tau ID Cuts	M(trk+π0), Isolation(trk,π0), anti-electron,…	**55.6±1.6(stat)±2.2(syst)%**
Event Topology	MT, HT: tight cuts against QCD, W+jets	**47.2±2.3(stat) ±3.5(syst)**
Total:		~1.0 %



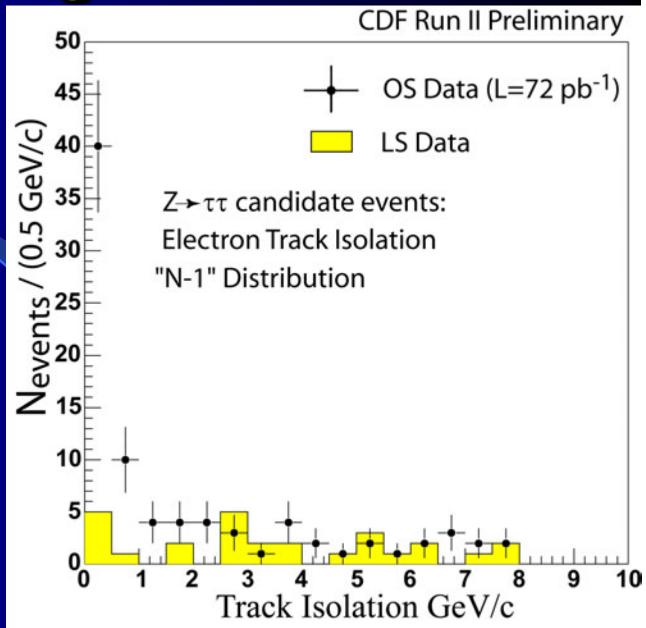


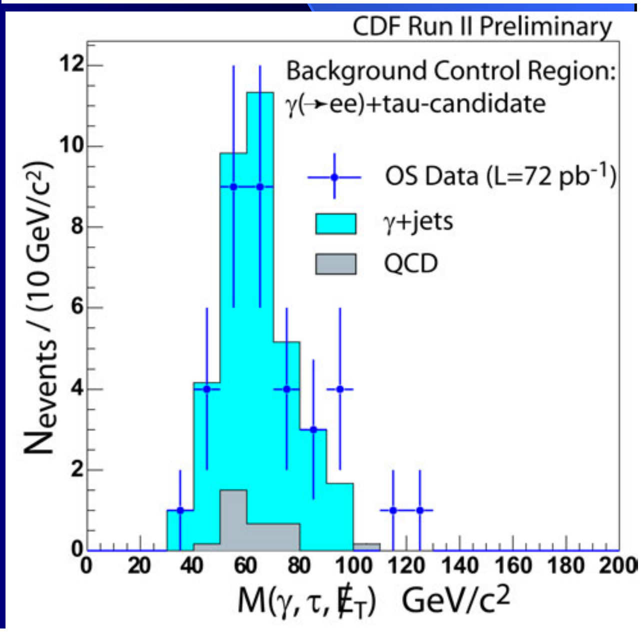
Background Estimation

- Avoid relying on MC simulation of jet-tau fake rates
  - e.g. track multiplicities in quark/gluon jets are off in both Pythia and Herwig
- Traditionally, we have been using jet-to-tau fake rates extracted from jet data, but
  - difficult to estimate fake rate with better than ~30% systematic uncertainty
  - One solution: suppress QCD to a very low level, so that 30% would not matter.
    - Often not possible
    - Signal statistics suffers dramatically
- $Z \rightarrow \tau\tau$ analysis: attempt a data-driven approach to separate backgrounds and address them one-by-one.

QCD, γ+jet, EWK Backgrounds

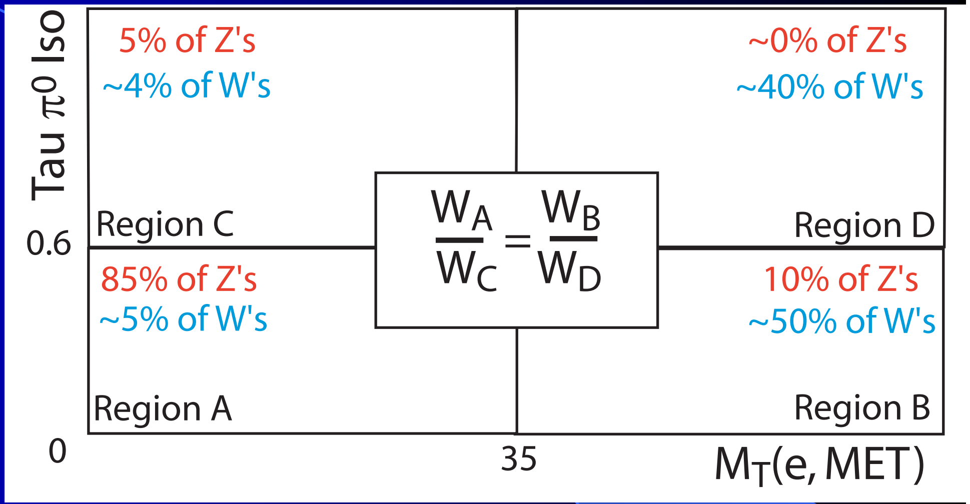
- QCD jet production:
  - Electron is a "fake" inside a jet
    - π^0 inside jet→γγ→conversion electron
    - Semi-leptonic b-jet decays
  - Typically has flat isolation distribution, e.g. see plot for LS (like-sign) events
  - Can extrapolate
- γ+jet(s):
  - real isolated electron or a converted photon escaping tagging
  - Study tagged converting γ+jet data
  - Fit the excess of isolated LS events over extrapolated QCD or use conversion tagging efficiency
- Z→ee (strong bremming electron), top, diboson:
  - Can get reliably from MC





Z vs W+jet Separation

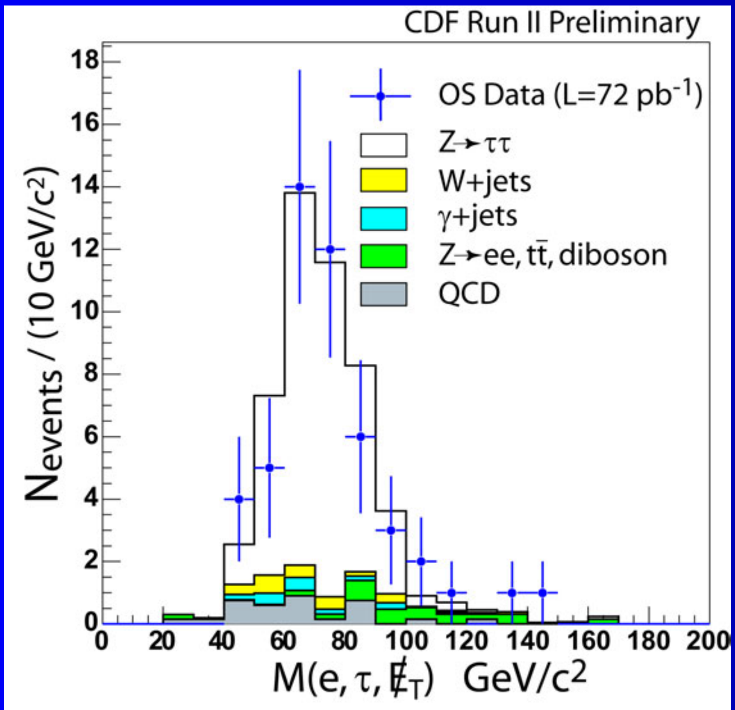
- W+jet with the cuts used is not that large, but hard to estimate
- Use transverse mass M_T(e,MET) and π^0 isolation
- Assume scaling of W's

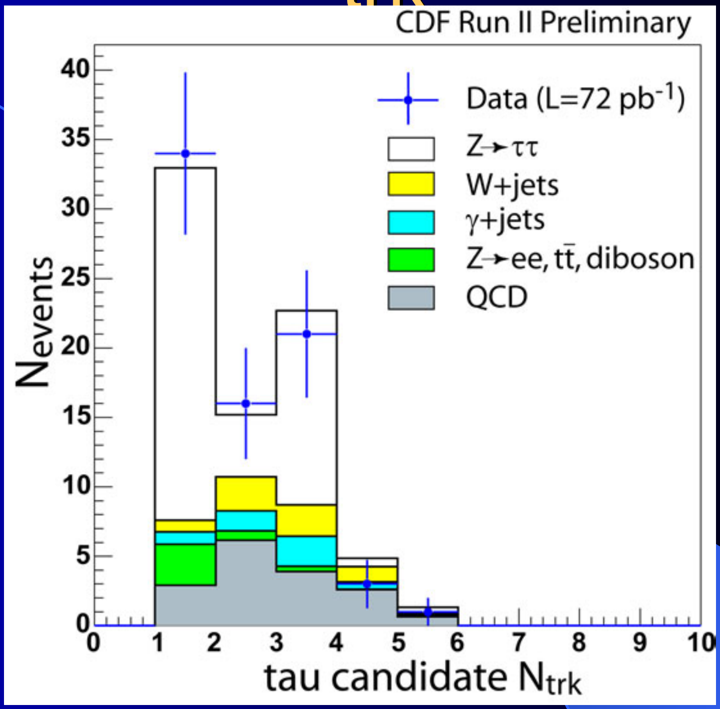


- Multi-dimensional fit in all 4 regions
  - Include all other backgrounds (QCD, EWK, γ+jet)
  - Use Z fractional efficiencies (derived from MC+Data)

Final $\sigma(Z)*Br(Z\rightarrow\tau\tau) = 242+48(stat)+26(syst)+15(lumi)\ pb^{-1}$

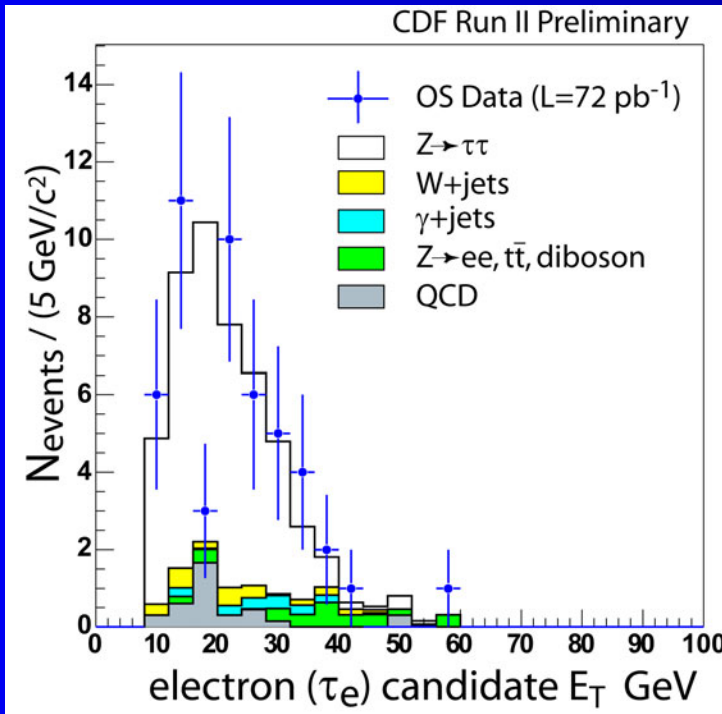
Z→ττ: Mass and N_{trk}

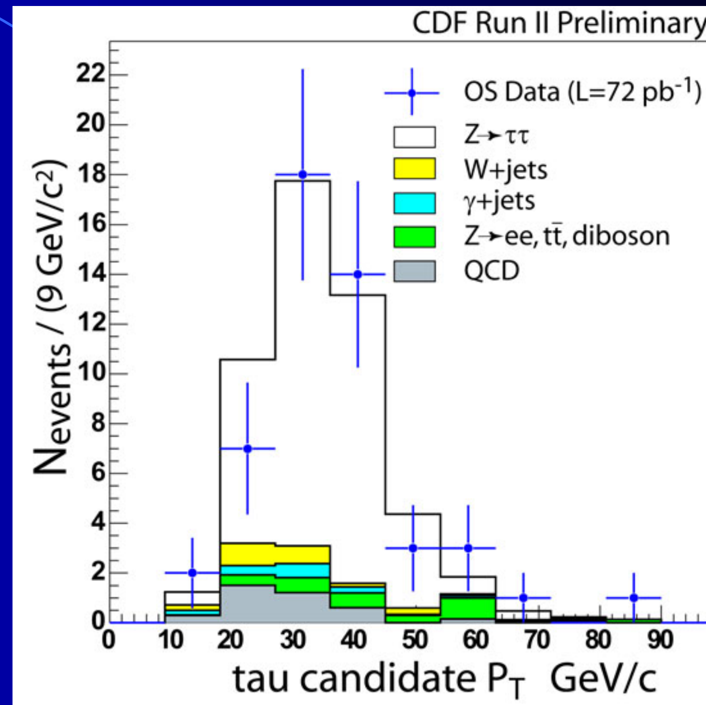




- Multiplicity: remove OS requirement
  - γ+jet shape is based on γ(→ee)+τ-candidate sample
  - Classic tau signature is quite evident even without OS cut

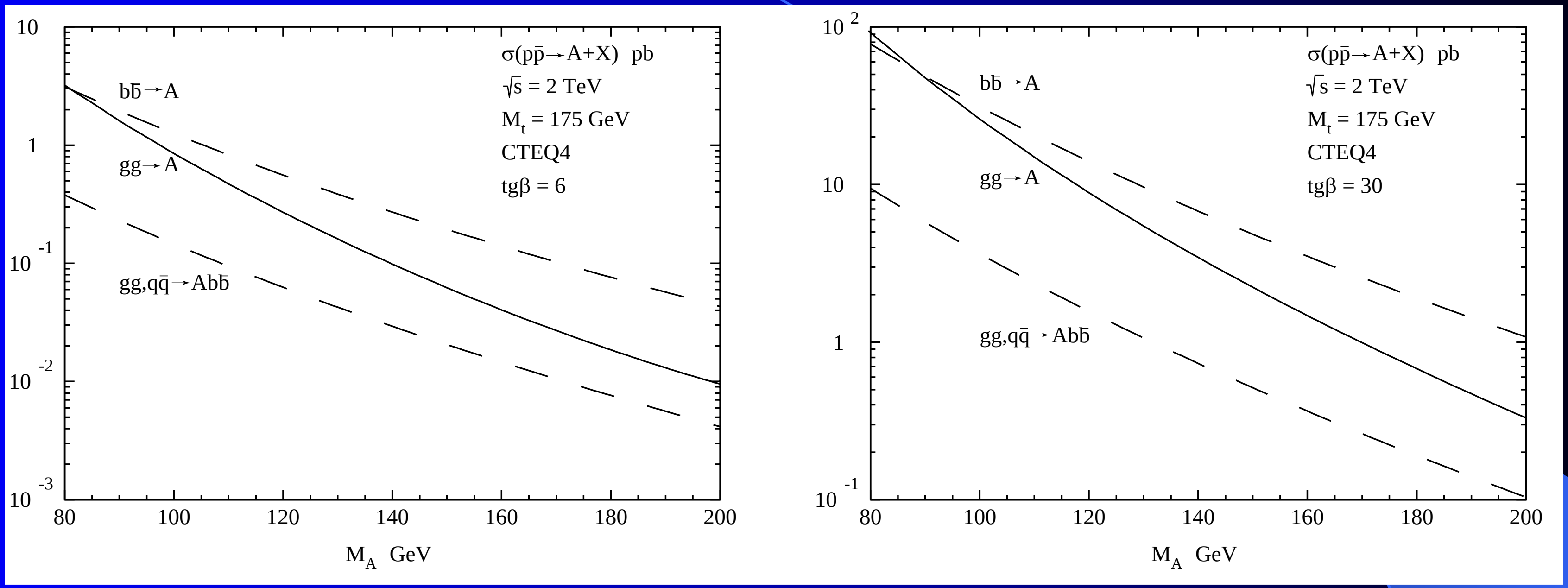
Z→ττ: Kinematics





- Electron E_T and Tau P_T distributions for OS data
- Shows need of tau reconstruction efficiency improvement at P_T~15-25 GeV

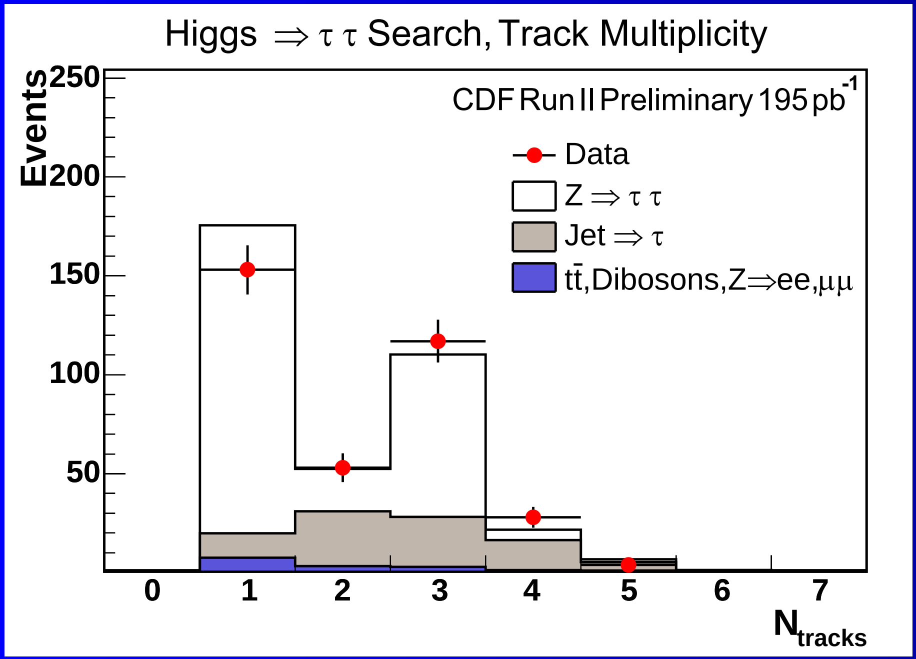
MSSM H→ττ



- MSSM Higgs:
  - Cross-section enhancement at large tanβ
  - Large NNLO corrections
  - Additional interest in light of high mass di-tau event in Run I

MSSM H→ττ

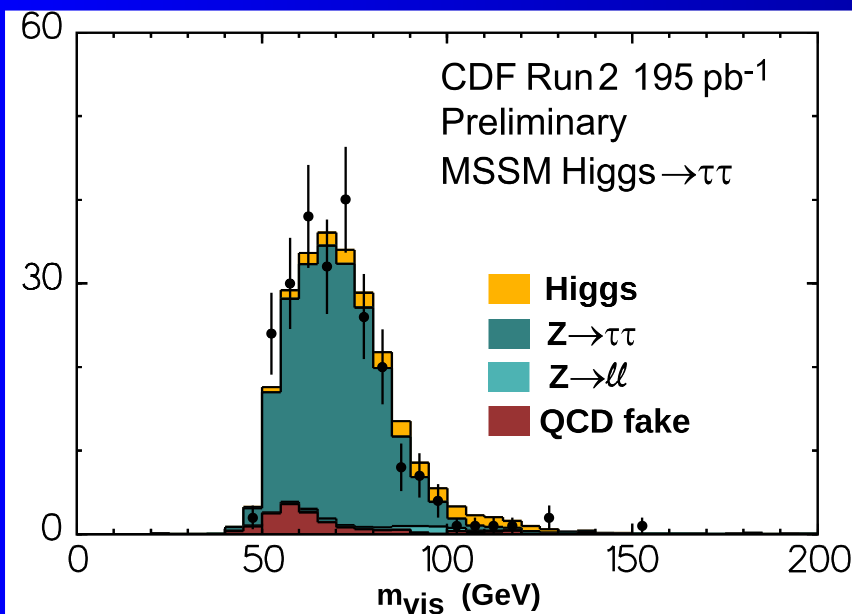
- eτ, μτ, ττ channels combined
- Slightly tighter tau ID cuts to further suppress backgrounds
- Fake rate technique for jet-induced backgrounds

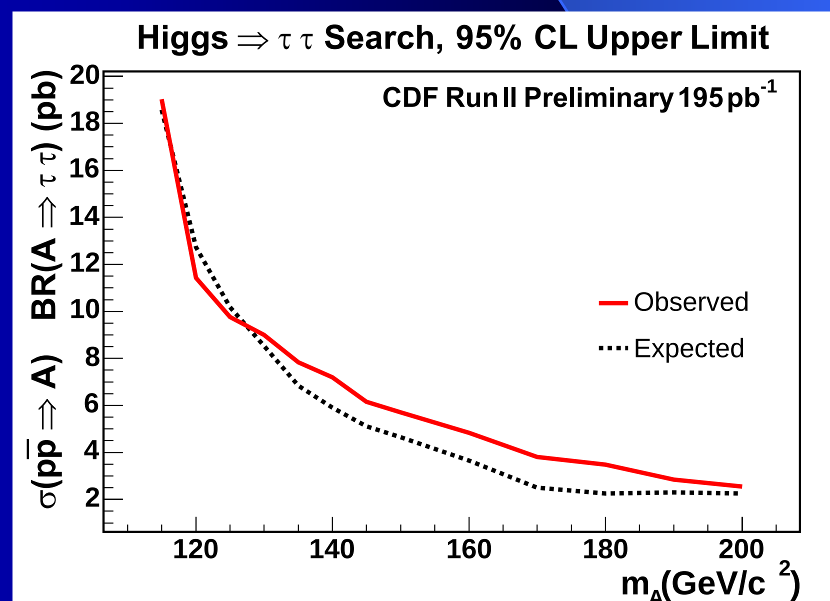


- Clean tau signature
- Backgrounds dominated by Z →ττ
- Look for excess in the mass plane (next slide)

MSSM H→ττ

- 200 pb^{-1} Search:
  - No excess is found
  - Limit on the cross-section is set
- Will be updating regularly as more data available





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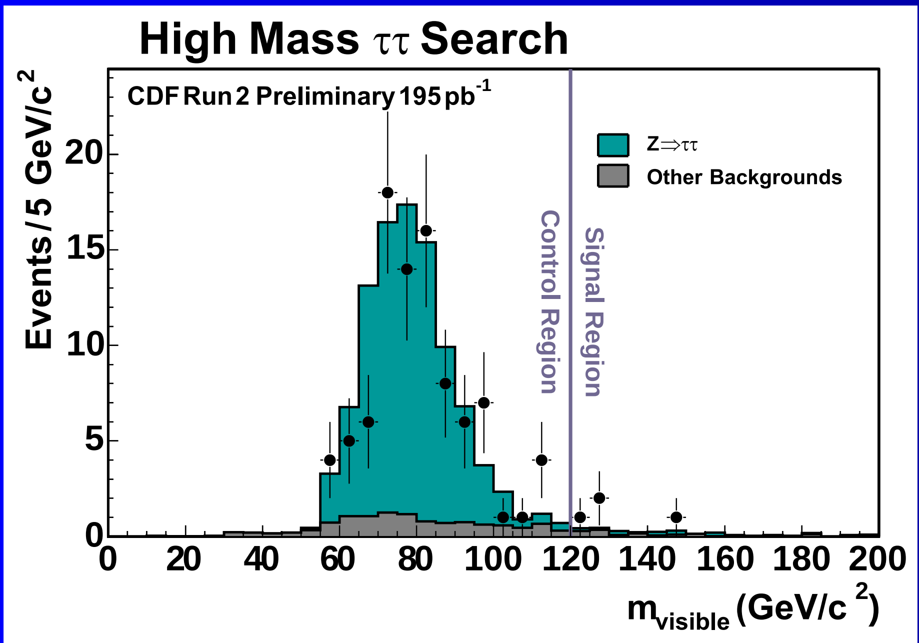
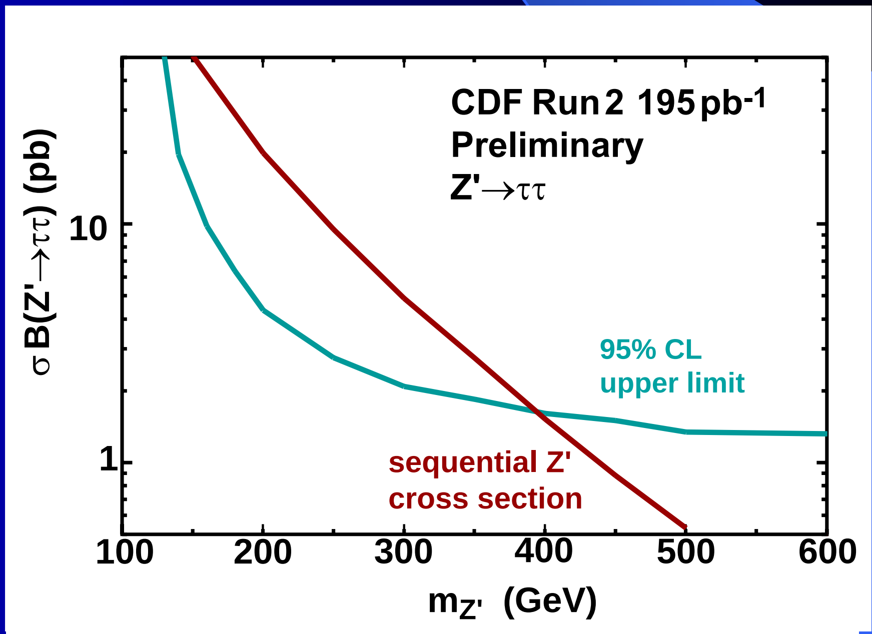
High Mass Z'→ττ

- Analysis similar to MSSM Higgs, but look for signal in higher mass region
- No excess is found. Limit is set on Z'
- Will be updating regularly with more data





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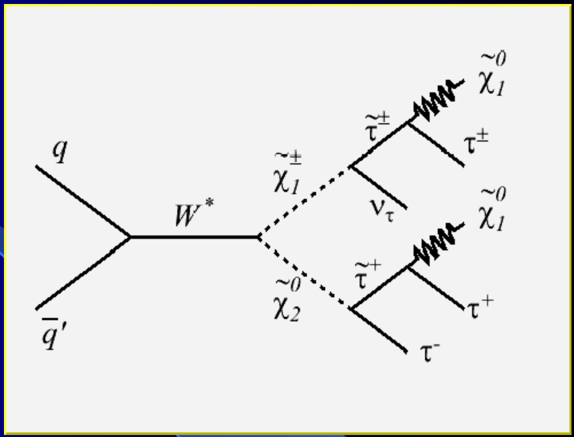
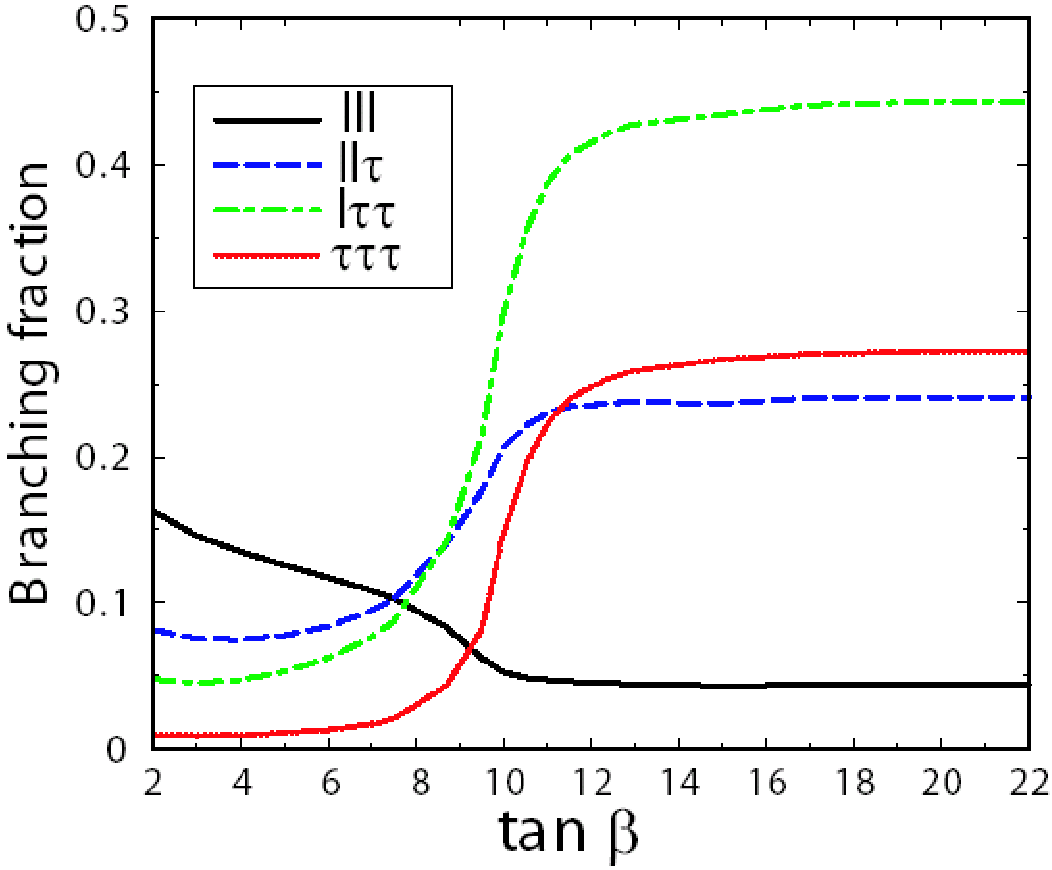
SUSY Tri-Leptons

- mSUGRA trilepton production:

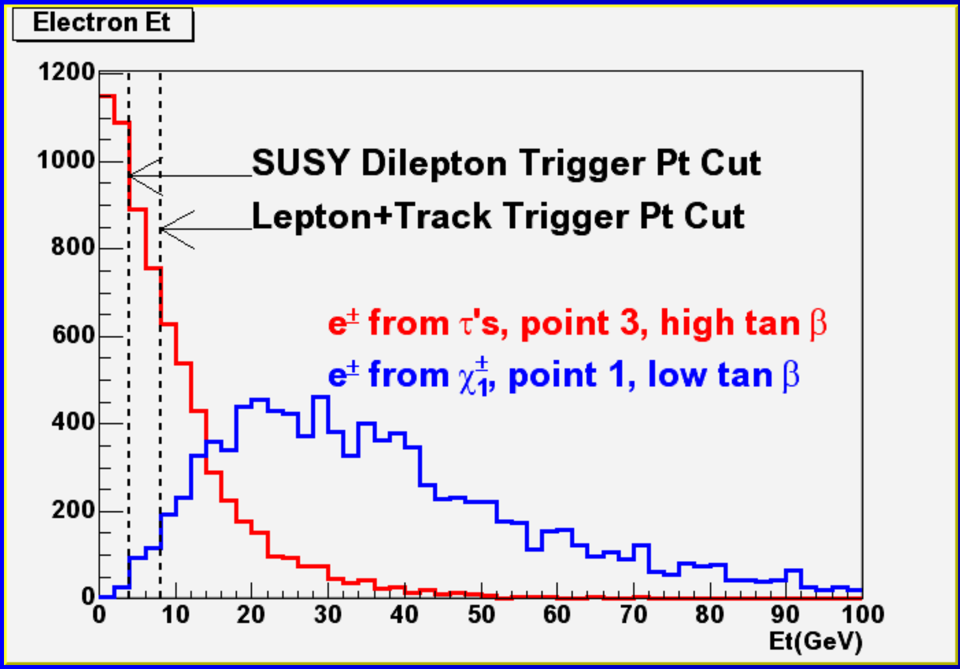
$$p\bar{p} \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow (\nu\tilde{l})(l\tilde{l}) \rightarrow (\nu l\tilde{\chi}_1^0)(ll\tilde{\chi}_1^0)$$





- Large tanβ is theoretically motivated
- At tanβ >8 final state leptons are dominated by τ's.
- Tau channels are very important!

SUSY Tri-Leptons

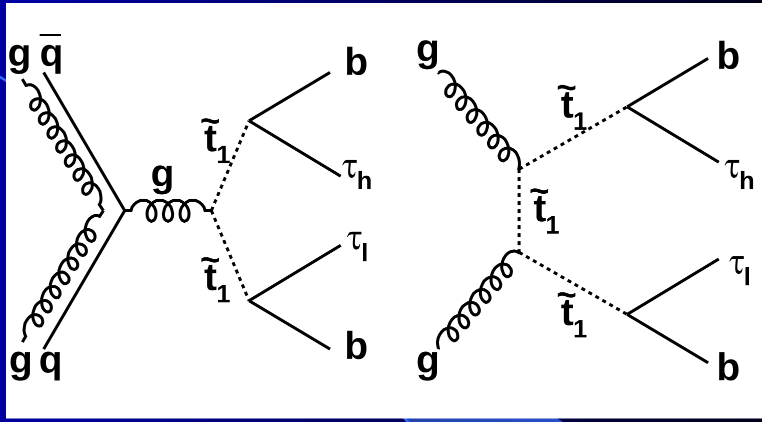


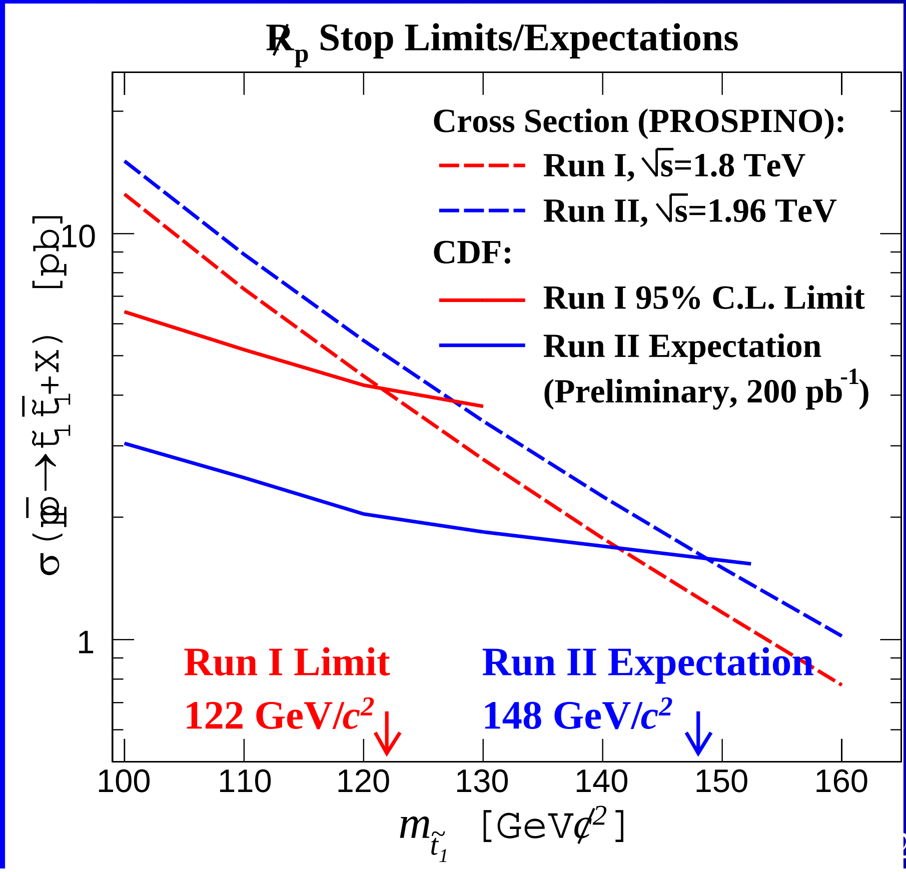
- We explore several points in SUSY parameter space, one point is at LEP-2 limit
  - Spectrum is very soft and acceptance is low
  - Expect 2 ev/fb^{-1} for trilepton search

- Search for Like-Sign Dileptons (LSD) yields ~3-4 ev/fb^{-1}, but backgrounds are high
  - Lots of work and Lumi is needed
  - Consider scenarios without universality of sfermion masses

RPV SUSY Stop/LQ_3

- If R-Parity is violated, stop→τb is allowed
- Kinematics/x-section are the same as 3rd generation scalar LeptoQuark

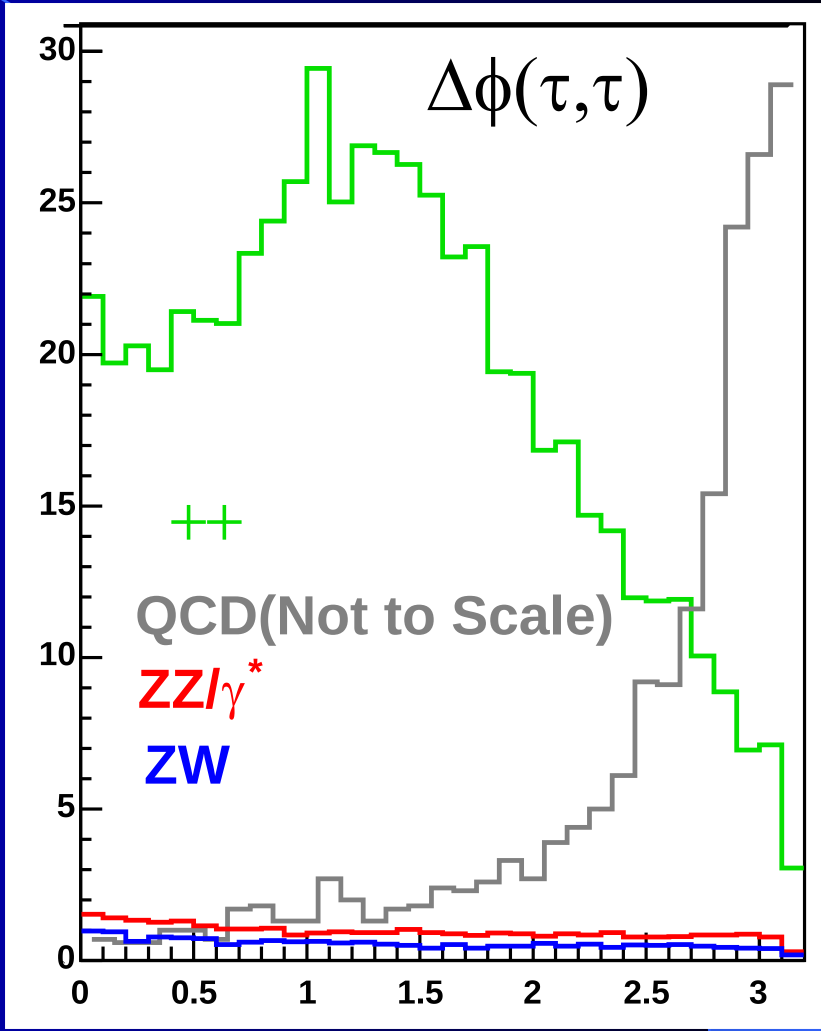




- Analysis very similar to Z→ττ
- $H_T^{'} = p_T^e + p_T^\tau + MET > 85\ GeV$
- Results out in November
- Large improvement in the reach is expected:
  - Run I stop: M>122 GeV
  - Run I scalar LQ: M>90 GeV
- Limits on Technicolor will follow

Double Charged H^{++}

- Appears in LR-symmetric SUSY models
- Couples to leptons only
- No experimental constraints for H++ decaying to taus
- Pair produced at the Tevatron
- Cross-section of the order of 400-100 fb for M(H)= 80-130 GeV
- Both H's have high P_T:
  - high acceptance
  - low backgrounds
- Results in early 2005



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Summary and Plans

- Tau Program at CDF is well underway
  - Good control of efficiency and backgrounds
  - First preliminary physics results are out
    - Z cross-section, MSSM Higgs search, High mass Z'
  - More results out in Winter'05
    - Stop search, 3rd generation LQ, H++, updated $Z \to \tau\tau$
  - mSUGRA tri-leptons will require more time and luminosity
- Planned improvements:
  - expanding triggers to higher pseudo-rapidity
  - Improving efficiency at intermediate P_T~15-30 GeV
- All this work helps build experience for LHC era