present status and perspectives

CDF II

# Physics with tau leptons

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# Outline

- *Motivations*
- *Tau Triggers & Tau ID*
- *Trigger Performances*
- *Physics Analysis in progress*
- *Plans for future*

# CDF-II $\tau$ Physics Program

## Electroweak

$$p\bar{p} \rightarrow Z^0 \rightarrow \tau^+\tau^-$$

$$p\bar{p} \rightarrow WZ^0 \rightarrow (\tau\nu)(\tau^+\tau^-)$$
$$(jj)(\tau^+\tau^-)$$

## Higgs

$$p\bar{p} \rightarrow WH^0 \rightarrow (\tau\nu)(\tau^+\tau^-)$$
$$(jj)(\tau^+\tau^-)$$

$$p\bar{p} \rightarrow ZH^0 \rightarrow (ll)(\tau^+\tau^-)$$
$$(jj)(\tau^+\tau^-)$$

$$p\bar{p} \rightarrow H^0/A^0/h^0 \rightarrow \tau^+\tau^-$$

$$p\bar{p} \rightarrow t\bar{t} \rightarrow (H^+b)(H^-b) \rightarrow (\tau^+\nu b)(\tau^-\nu b)$$

$$p\bar{p} \rightarrow h^0 \rightarrow \tau^\pm\mu^\mp$$

## SUSY (MSSM/SUGRA/RPV)

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

$$p\bar{p} \rightarrow \tilde{t}_1\bar{\tilde{t}}_1, (\tilde{t}_1 \rightarrow b\tau) \rightarrow (bl\nu_\tau)(\bar{b}\tau_h)$$

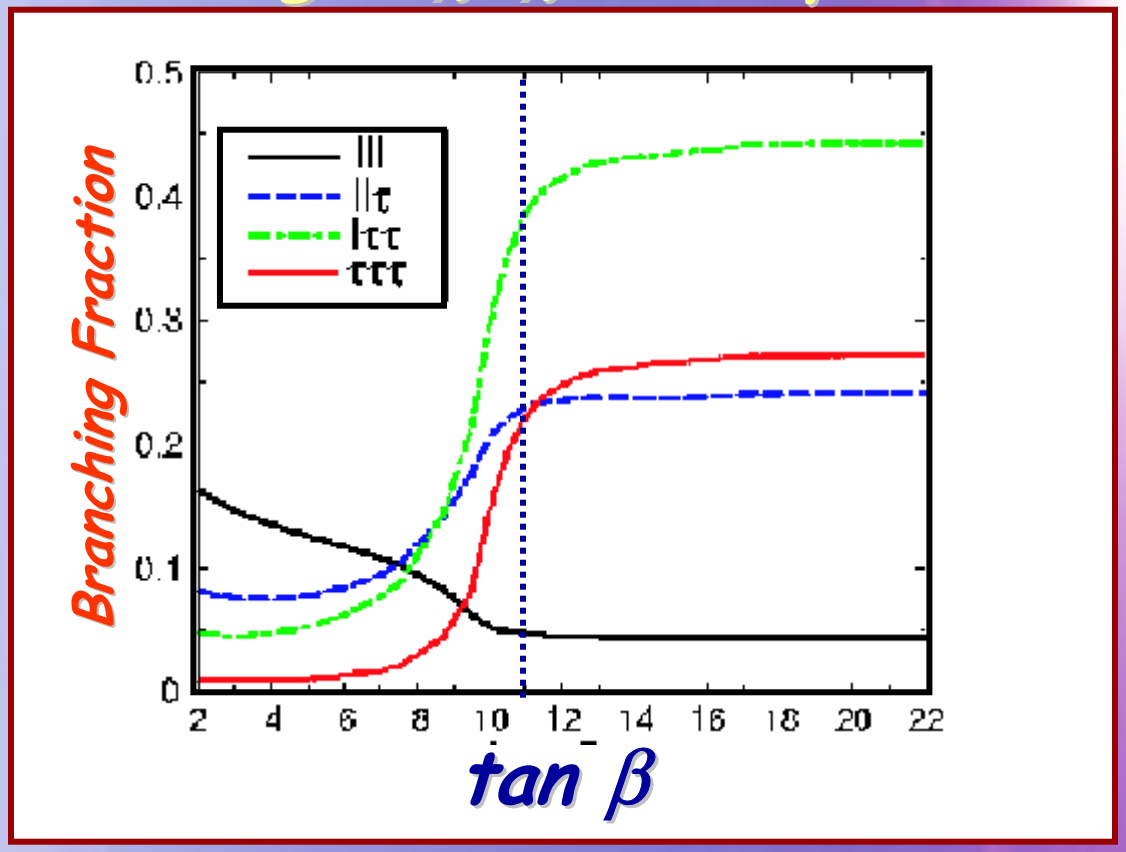
## Top

$$p\bar{p} \rightarrow t\bar{t} \rightarrow (W^+b)(W^-b) \rightarrow (\tau^+\nu b)(\tau^-\nu b)$$

**$\tau$ based signatures enhance Run II discovery potential for New Physics**

# $\tau$ Branching Fraction vs tan $\beta$

## MSugra $\chi^{\pm}\chi^{0}$ tri-leptons




just to get the feeling...

# Physical Motivations (II): $\sigma(Z^0 \to \tau\tau)$

- $\sigma(Z^0 \to \tau\tau)$, never measured before at Tevatron;
- Benchmark for many $\tau$-related analyses;
- Main irreducible background for most searches for physics beyond the SM:
  - Higgs (SM, SUSY, LFV);
  - Chargino-Neutralino Production (tan $\beta$ >>1);
  - RPV SUSY decays;
- Testing sample in order to:
  - understand $\tau$ reconstruction;
  - develop background techniques;
  - tuning efficiencies;

# $\tau$ Triggers



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# CDF-II Tau Triggers

## 5 Tau Triggers

1. Central $\mu$ + Track
2. "Forward" $\mu$ + Track
3. Electron + Track

$\tau_1 \rightarrow l\ \nu_l$

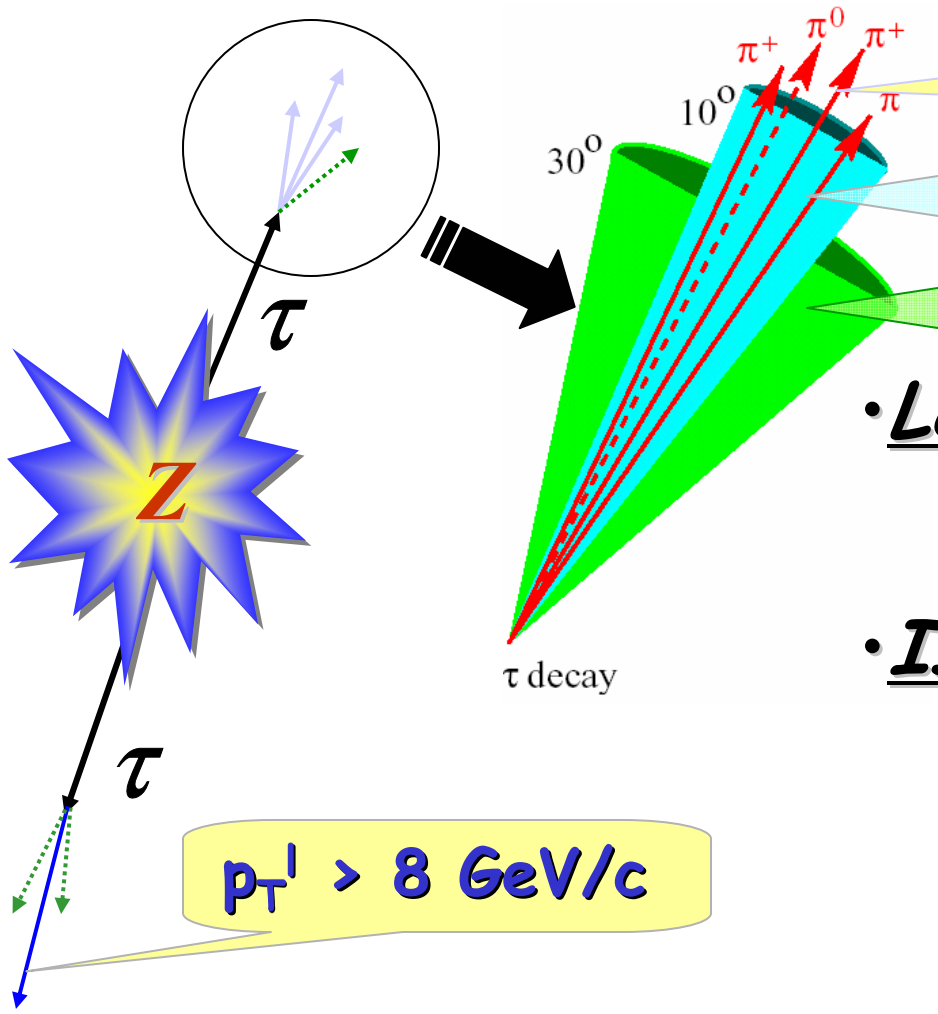
$\tau_2 \rightarrow hadrons$

4. Di-$\tau$ Trigger
5. $\tau$ + $\not\!\!E_T$

$\tau \rightarrow hadrons$

**In the Trigger Table since Jan 2002**

# Lepton+Track Trigger (the concept)




$p_T^{seed}$ > 5 GeV/c

Tau Cone

Isolation Cone

- **Lepton ($e,\mu$)**
  Lower $P_T$ Threshold
- **Isolated track**
  No tracks in 10-30° Cone

**No prescale with high luminosity !!**

# Lepton+Track vs other Triggers

*Low $P_T$ thresholds !*

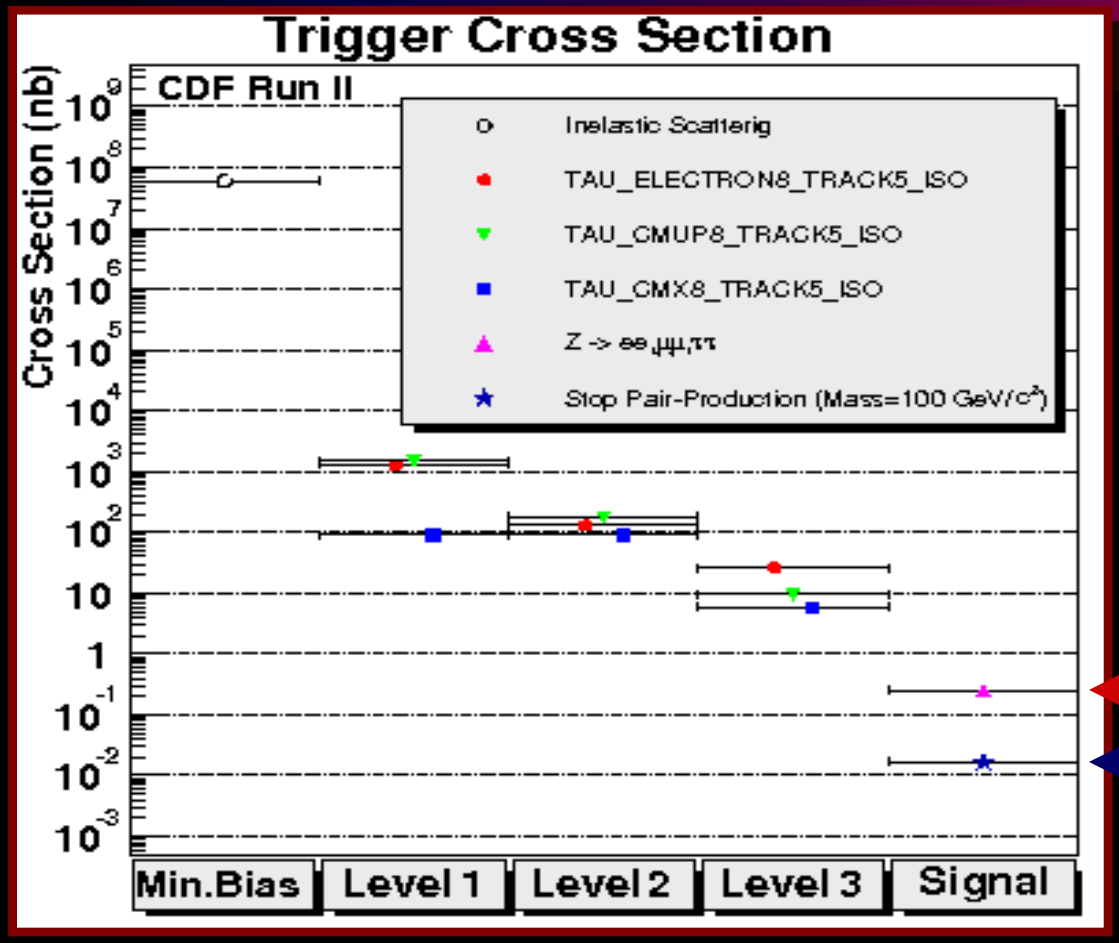
| *Trigger* | *$\eta$ coverage* | *Thresholds* |
|---|---|---|
| *Lepton+track* | $\|\eta\| < 1$ | $E^e_T$ ( $p^\mu_T$ ) > 8 GeV<br>Track $P_T$> 5 GeV/c |
| *Di-tau* | $\|\eta\| < 1$ | $E^\tau_T$ > 6 GeV |
| *Tau –MET* | $\|\eta\| < 1$ | $E^\tau_T$ > 20 GeV<br>$E_T$ (MET)> 20 GeV |
| *Inclusive e* | $\|\eta\| < 1$ | $E_T$ > 18 GeV |
| *Inclusive $\mu$* | $\|\eta\| < 1$ | $p^\mu_T$ > 18 GeV/c |

# *Lepton+Track Trigger Logic*

| | Electron8+Track5 | CMUP Muon8+Track5 | CMX Muon8+Track5 |
|---|---|---|---|
| **L1** | Tower EM $E_T$> 8 GeV<br>Had/EM < 0.125<br>Matched track $P_T$>8 GeV/c | CMU Muon stub $P_T$> 6 GeV/c<br>Matching Track $P_T$> 4 GeV/c<br>CMP Stub matches track | CMX Muon stub<br>Matching Track $P_T$> 8 GeV/c |
| **L2** | EM Cluster $E_T$> 8 GeV<br>Cluster Had/EM< 0.125<br>Matching Track $P_T$>8 GeV/c<br>Matched ShowerMax $E_T$>2 GeV<br>$2^{th}$ Track $P_T$> 5 GeV/c<br>$\Delta\phi$(e, $2^{th}$ Track)> $10^0$ | Auto-Accept<br>(L2 muon hardware missing) | Auto-Accept<br>(L2 muon hardware missing) |
| **L3** | Loose Electron $E_T$>8 GeV/c<br>Tau-like Track $P_T$>5 GeV/c | CMUP muon $P_T$> 8 GeV/c<br>Tau-like Track $P_T$> 5 GeV/c | CMX Muon $P_T$>8 GeV/c<br>Tau-like Track PT>5 GeV/c |

# Trigger Performances

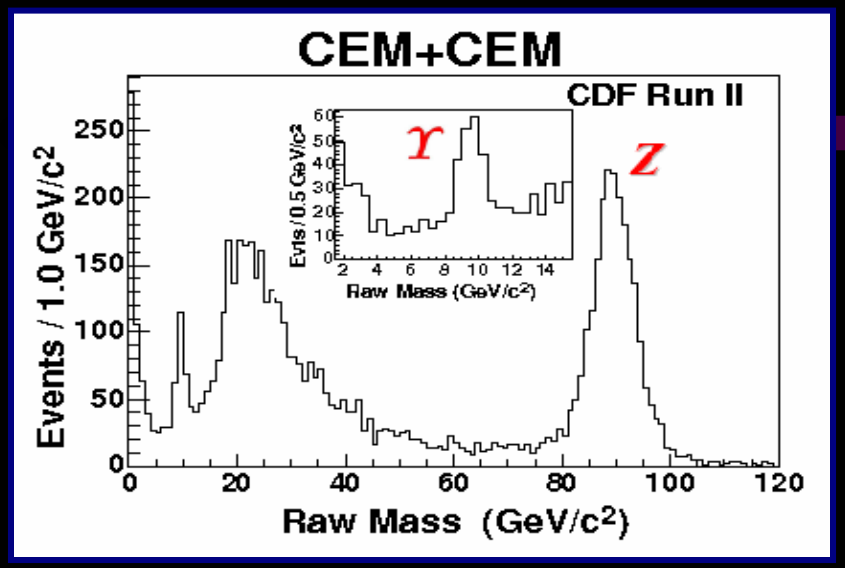
## *L1, L2, L3 LPT Trigger Cross Sections*

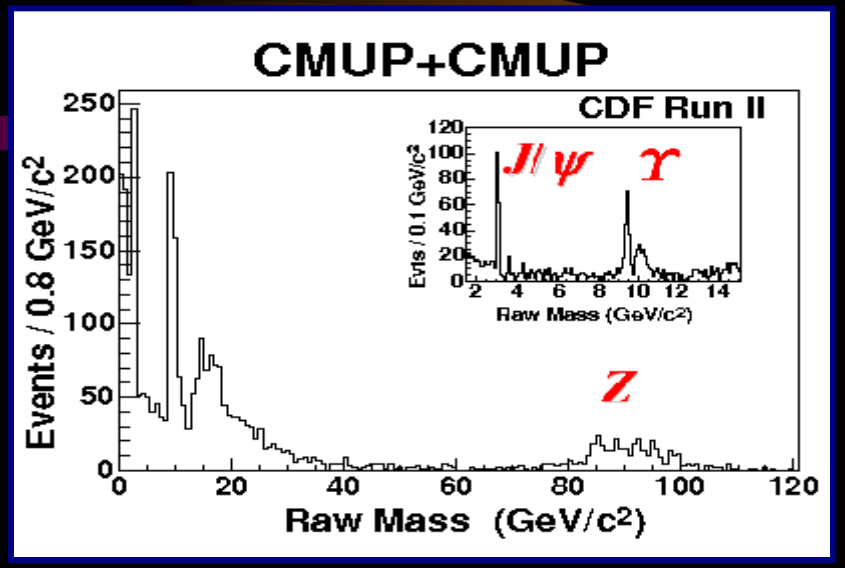


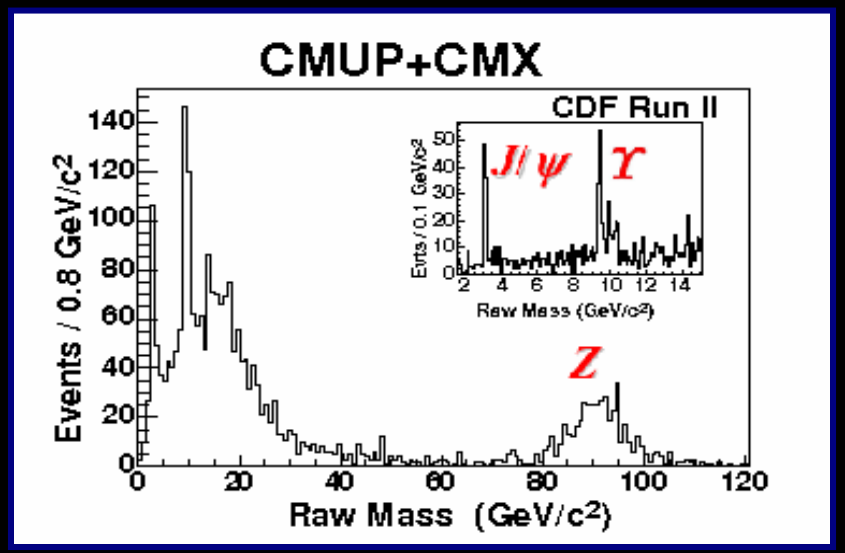

$Z \to ll$

$\tilde{t}_1\bar{\tilde{t}}_1 \to \tau_h \tau_\mu b\bar{b}$

# Dilepton invariant masses



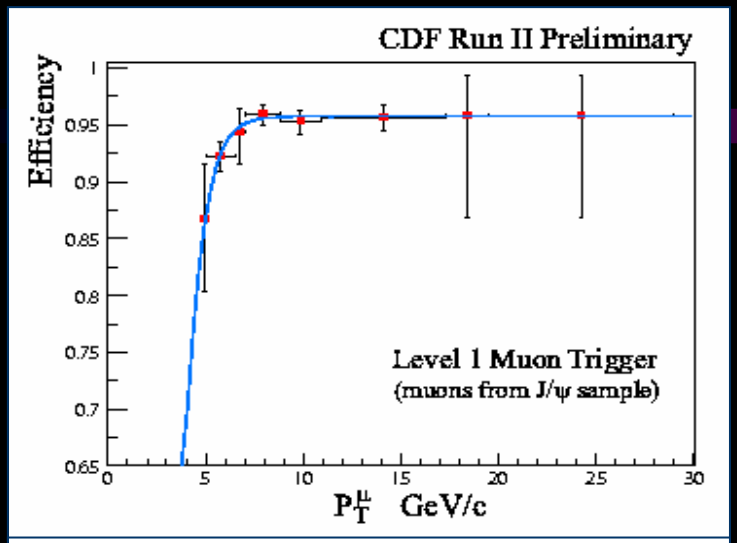



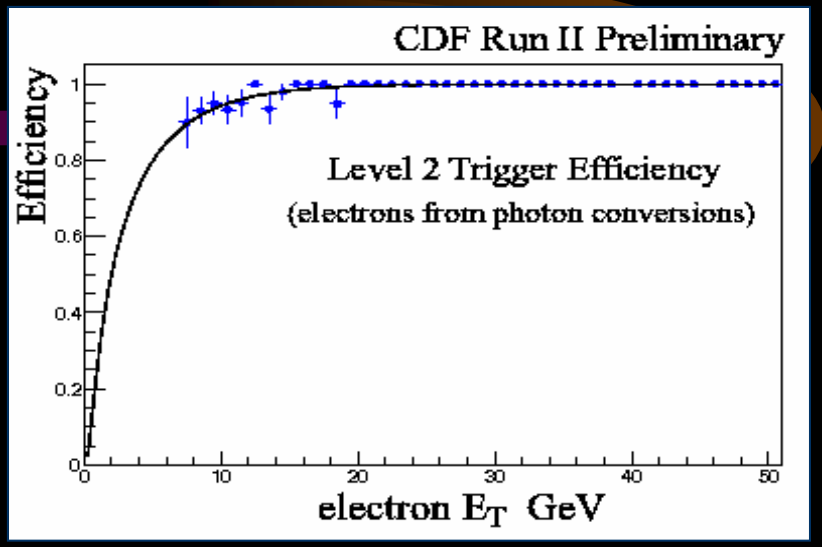



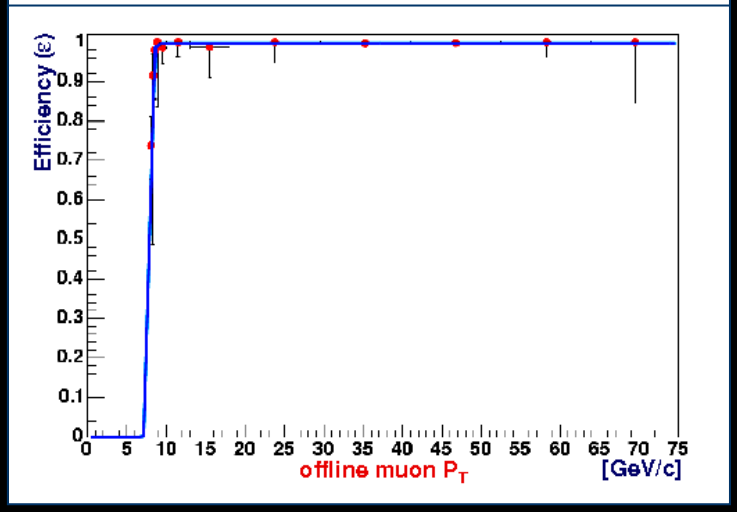

**Opposite-sign di-lepton Spectrum taken by LTT**

- *data Jan-Dec 2002, L ~ 100 pb$^{-1}$*
- *conversion/cosmic ray removal*
- *clear di-lepton signals*

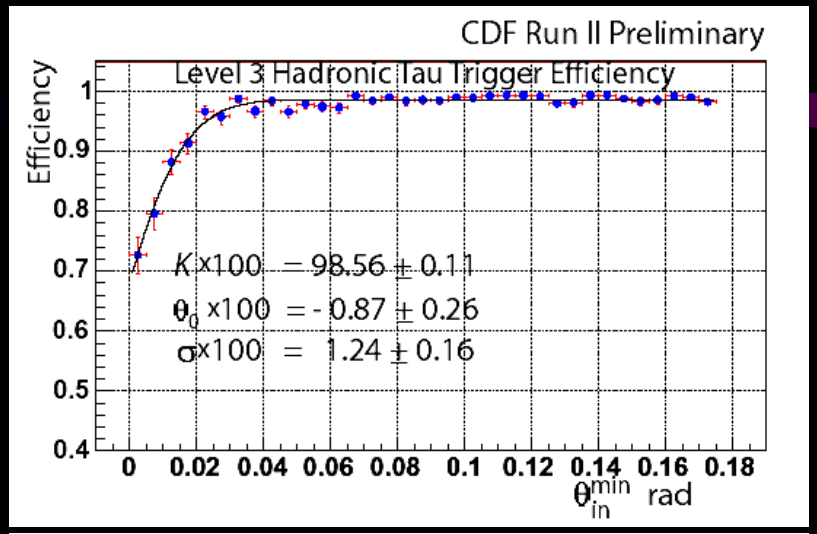
# Trigger efficiencies (I)

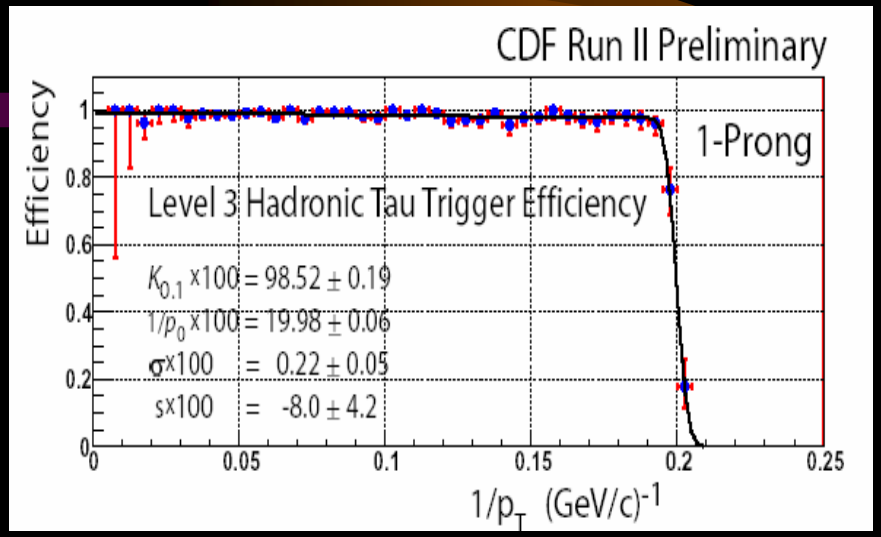


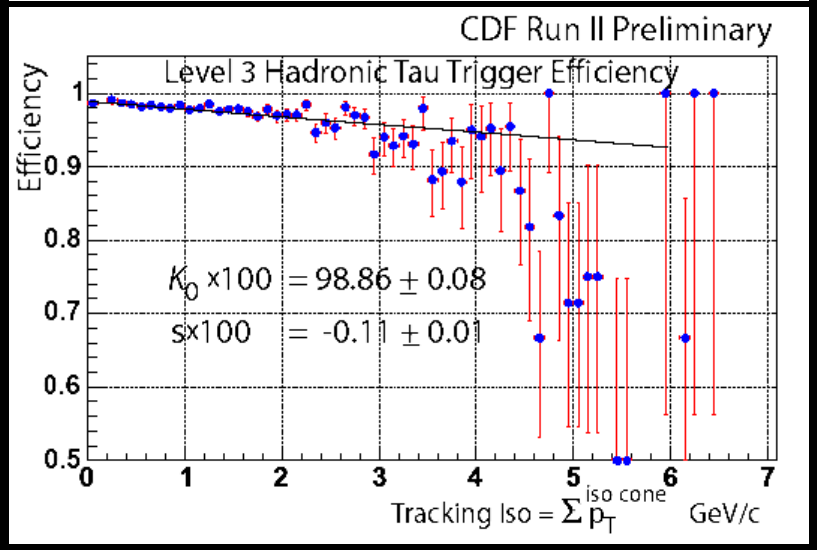



# Trigger Efficiencies (II)




## Level 3 Hadronic Tau

# LPT Trigger evolution

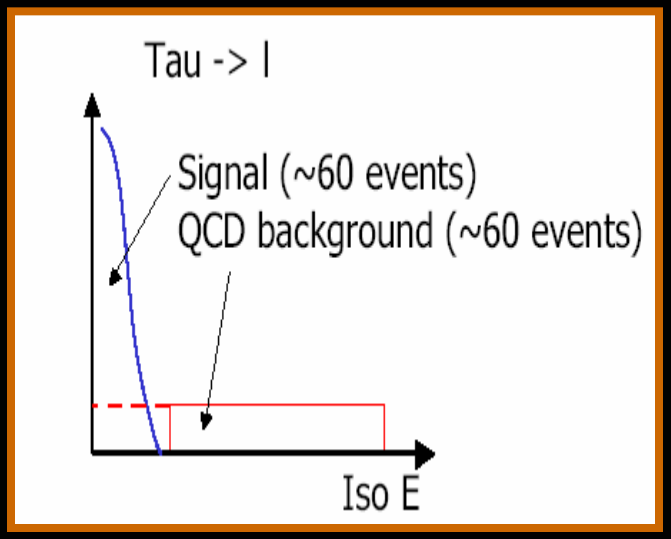
Current:

L2 => Isolated Tau (Track Filter) = Tau_Lepton sample
Lepton (Muon || Ele Filters)

Now testing...

Next:

L2 => Non-Isolated Tau (Track Filter)
Lepton (Muon || Ele Filters) => Tau_Lepton sample
TwoTrackFilter (Lepton ne Track)




- ✓ LPT runs without prescale;
- ✓ Track Iso can be dropped – still inside trigger bandwidth;
- ✓ Few changes needed;
- ✓ This will allow to use τ Iso(E);
- ✓ Extend e+track to Plug region

# $\tau$ ID



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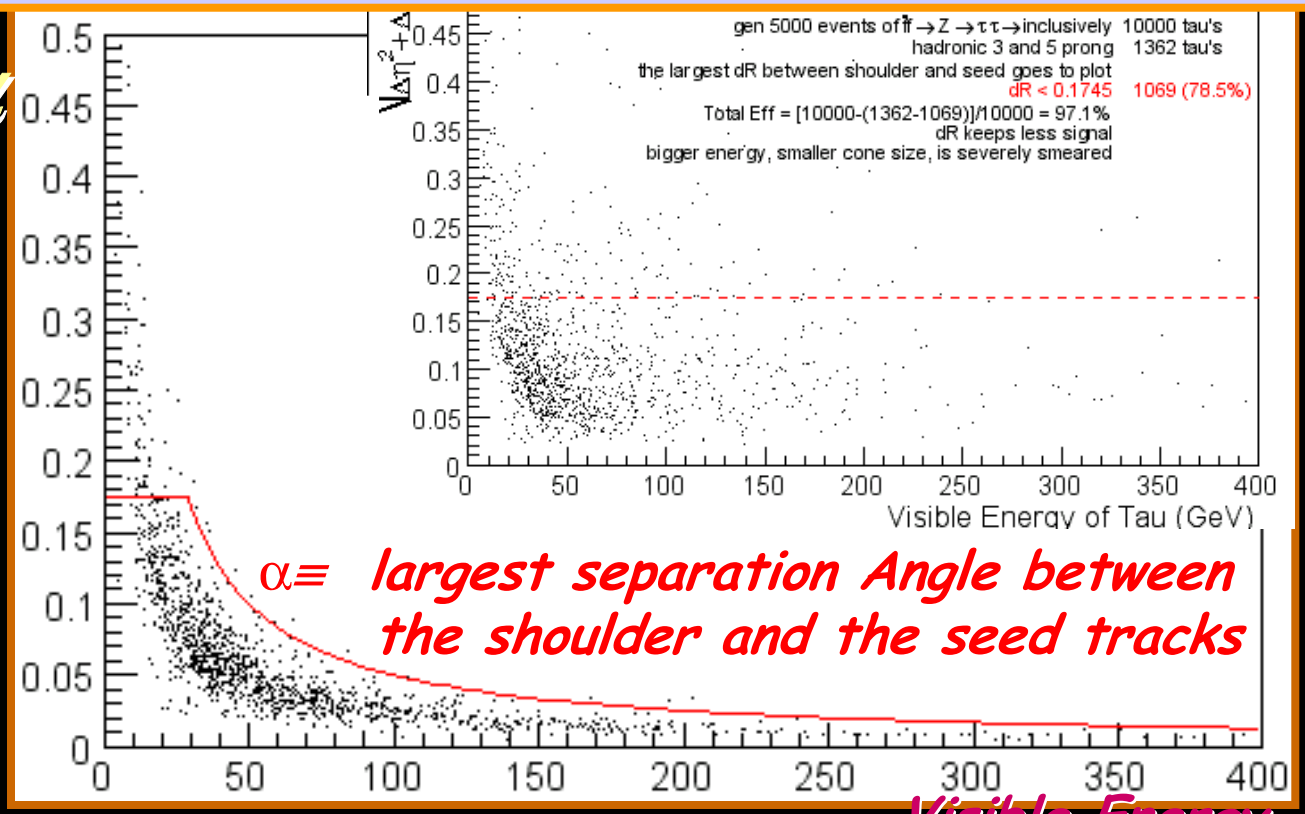
# Offline Tau Cone definition the shrinking cone approach

*Lorentz invariance is preserved*

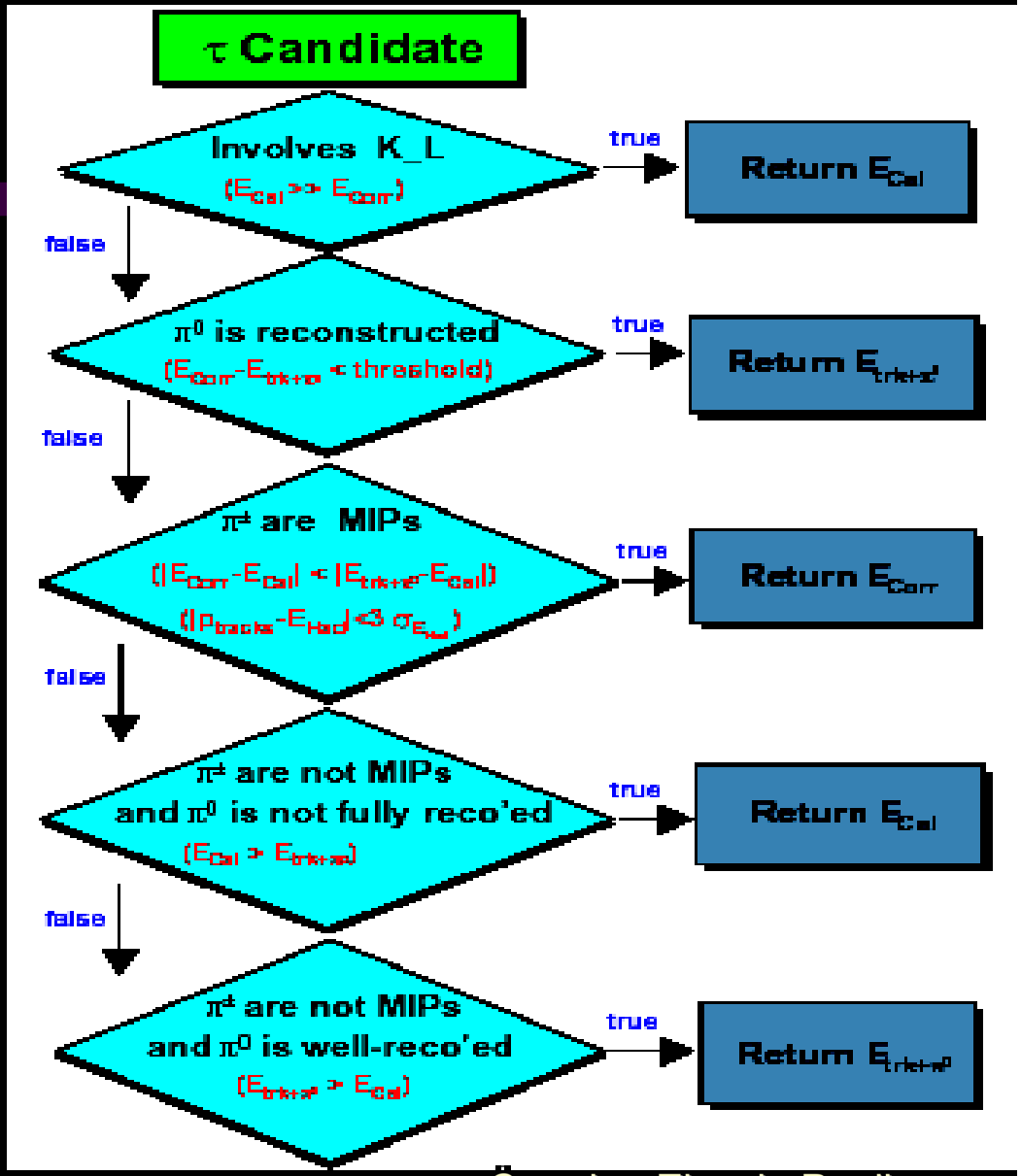
$\alpha = \max[\min(0.2\ \text{rad}, (5\ \text{GeV}\cdot\text{rad})/E_{\tau\_vis}), 0.005\ \text{rad}]$



# New Energy Estimates

Developed new method for E($\tau$) reconstruction:

- **9%** more 1-prong $\tau$
  E(Reco) ≅ E(MC) ± 10%
- **4%** more 3-prong $\tau$
  E(Reco) ≅ E(MC) ± 10%
- Robust against mis-reconstruction of $\pi^0$
- Robust against Had Calorimeter E-scale



# Run II: Preliminary Results

IFAE 2004 Torino, 14 Aprile 2004

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# Status of


# analysis @ CDF II

## the electron channel

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# Electron baseline selection

## Electron ID cuts

| Electron Variables | Cuts |
|---|---|
| $E_T$ | $> 10$ GeV |
| $p_T$ | $> 8$ GeV/$c$ |
| $E^{had}/E^{em}$ | $< 0.055 + 0.00045 \times E$ |
| $E/p$ | $< 4.0$ (for $E_T > 50$ GeV) |
| $L_{shr}$ | $< 0.2$ |
| $\lvert\Delta x\rvert$ | $-3.0 < Q_{trk} \cdot \Delta x < 1.5$ cm |
| $\lvert\Delta z\rvert$ | $< 3$ cm |
| $\chi^2_{strip}$ | $< 10$ |
| $\lvert z_0\rvert$ | $< 60$ cm |
| $Iso^{cal}$ ($\Delta R$=0.4) (with leakage correction) | $< 3$ GeV |
| ($Iso^{trk}$ during stripping) | ($< 0.2$) |
| $N_{\text{axial SL}}, N_{\text{stereo SL}}$ (for seed track) | $\geq 3$ |
| Fiducial | FidEle = 1 |
| | Conversion Removal |

## $Z \rightarrow e^+e^-$ Removal

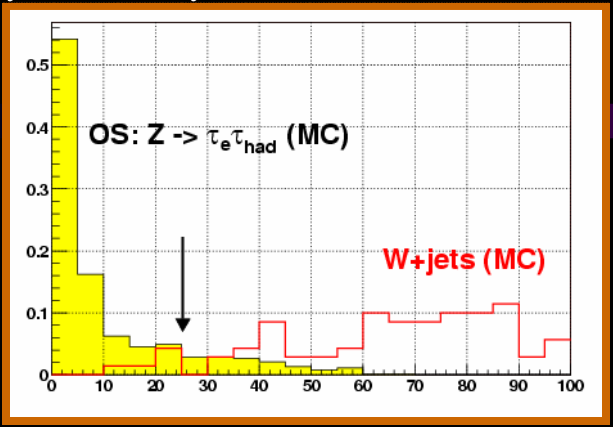
| | Cuts |
|---|---|
| Calorimeter-base | $E_T > 8$ GeV |
| | $E^{had}/E^{em} < 0.12$ |
| | Opposite Sign |
| | $75 < M(e, EmObj) < 105$ GeV/$c^2$ |
| Track-base | $p_T^{trk} > 10$ GeV/$c$ |
| | $Iso^{trk} < 0.05$ |
| | $\lvert z_0^{trk} - z_0^{ele}\rvert < 8$ cm |
| | Opposite Sign |
| | $60 < M(e, trk) < 110$ GeV/$c^2$ |

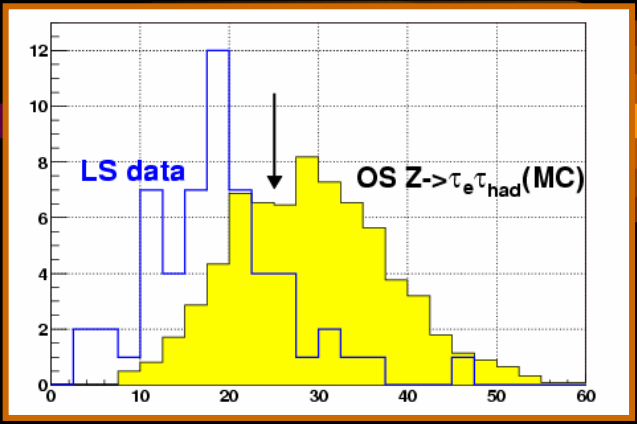
# $\tau_h$ Selection

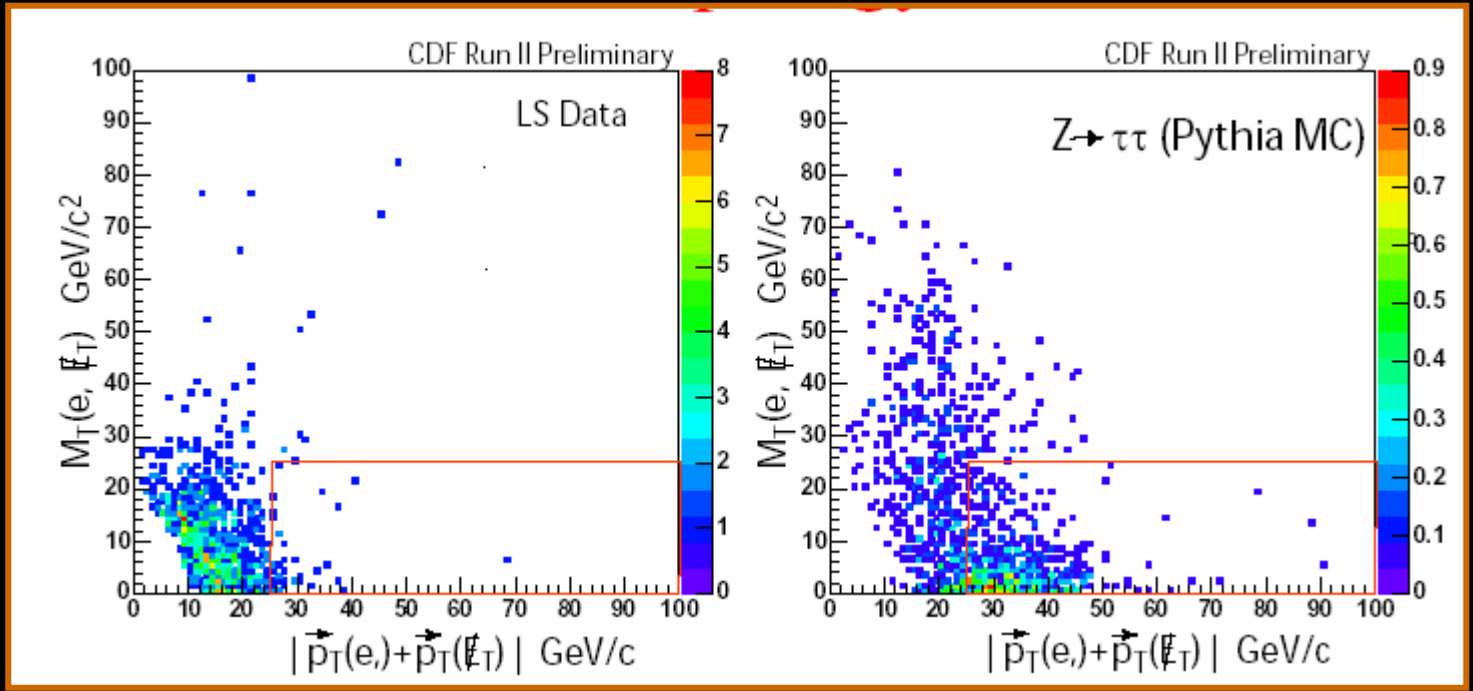
| Tau Variables | Cuts |
|---|---|
| $\lvert\eta_{det}\rvert$ | $< 1.0$ |
| $E_T^{clu}$ | $> 20$ GeV |
| Seed Tower $E_T$ | $> 6$ GeV |
| Seed Track $p_T$ | $> 6$ GeV/$c$ |
| Mass(tracks+$\pi^0 s$) | $< 1.8$ GeV/$c^2$ |
| Cal Iso ($\Delta R$=0.4) / $E_T^{clu}$ | $< 0.1$ |
| $\lvert z_0(\tau) - z_0(e)\rvert$ | $< 5$ cm |
| $N_{\text{axial SL}}, N_{\text{stereo SL}}$ (for seed track) | $\geq 3$ |
| $N_{track}^{\text{iso cone}}$ ($p_T > 1.0$ GeV/$c$) | 0 |
| $N_{\pi^0}^{\text{iso cone}}$ ($E_T > 0.5$ GeV) | 0 |
| Electron Removal | $\xi \equiv E_T^{had}/\Sigma\lvert p_T\rvert > 0.1$ |
| Fiducial Region | $9 < \lvert z_{CES}\rvert < 230$ cm |

# $M_T(e,\not{E}_T)$ and $P_T(e,\not{E}_T)$ Topology

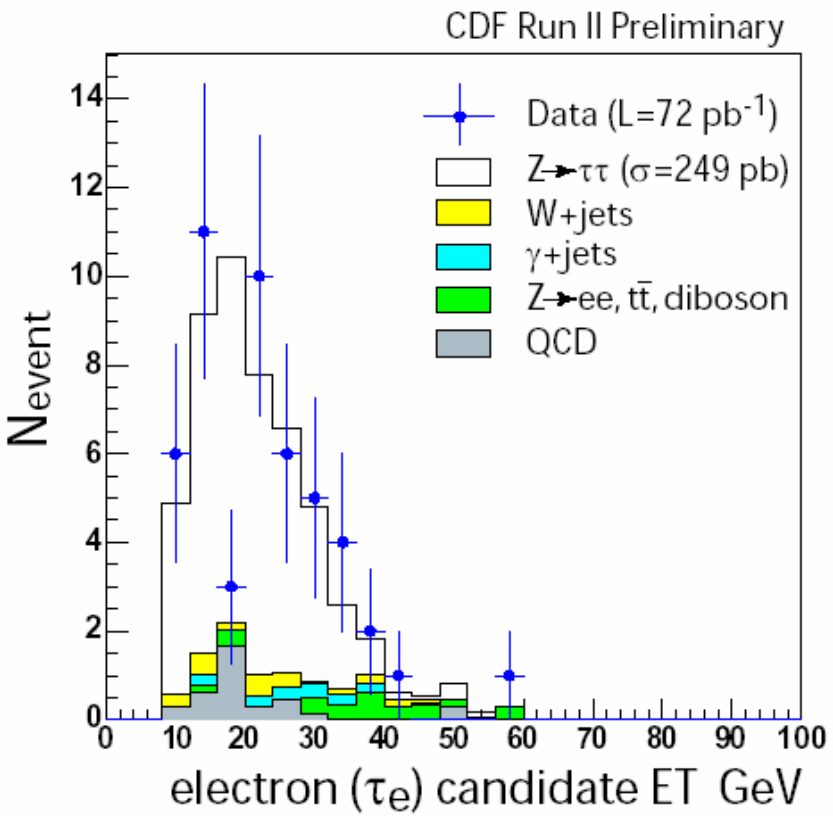
## $M_T(e,\not{E}_T) \geq 25$ GeV/$c^2$ $P_T(e,\not{E}_T) \geq 25$ GeV/$c$

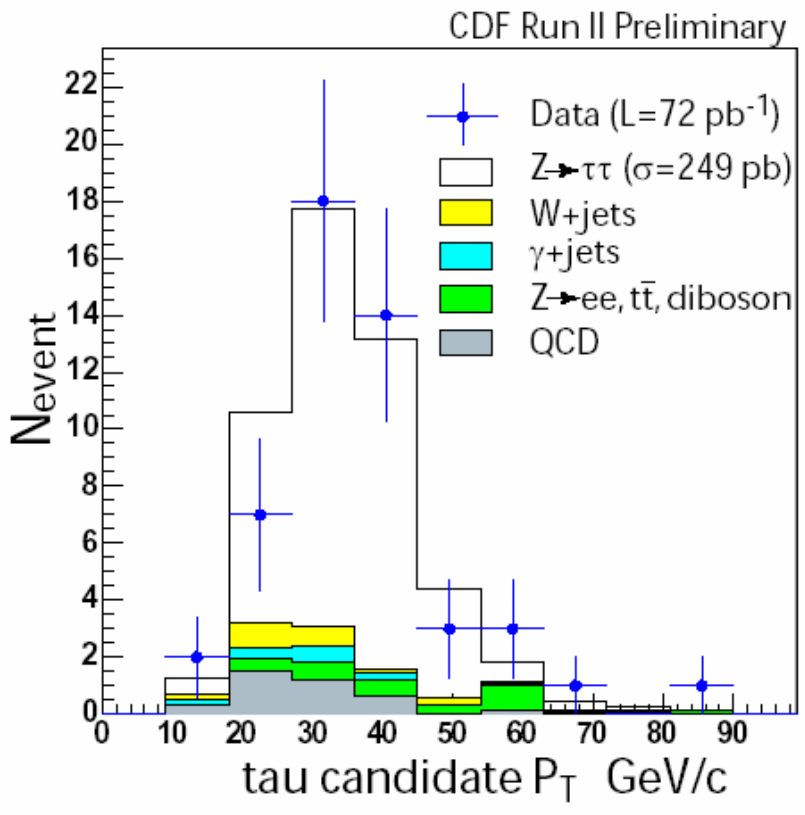


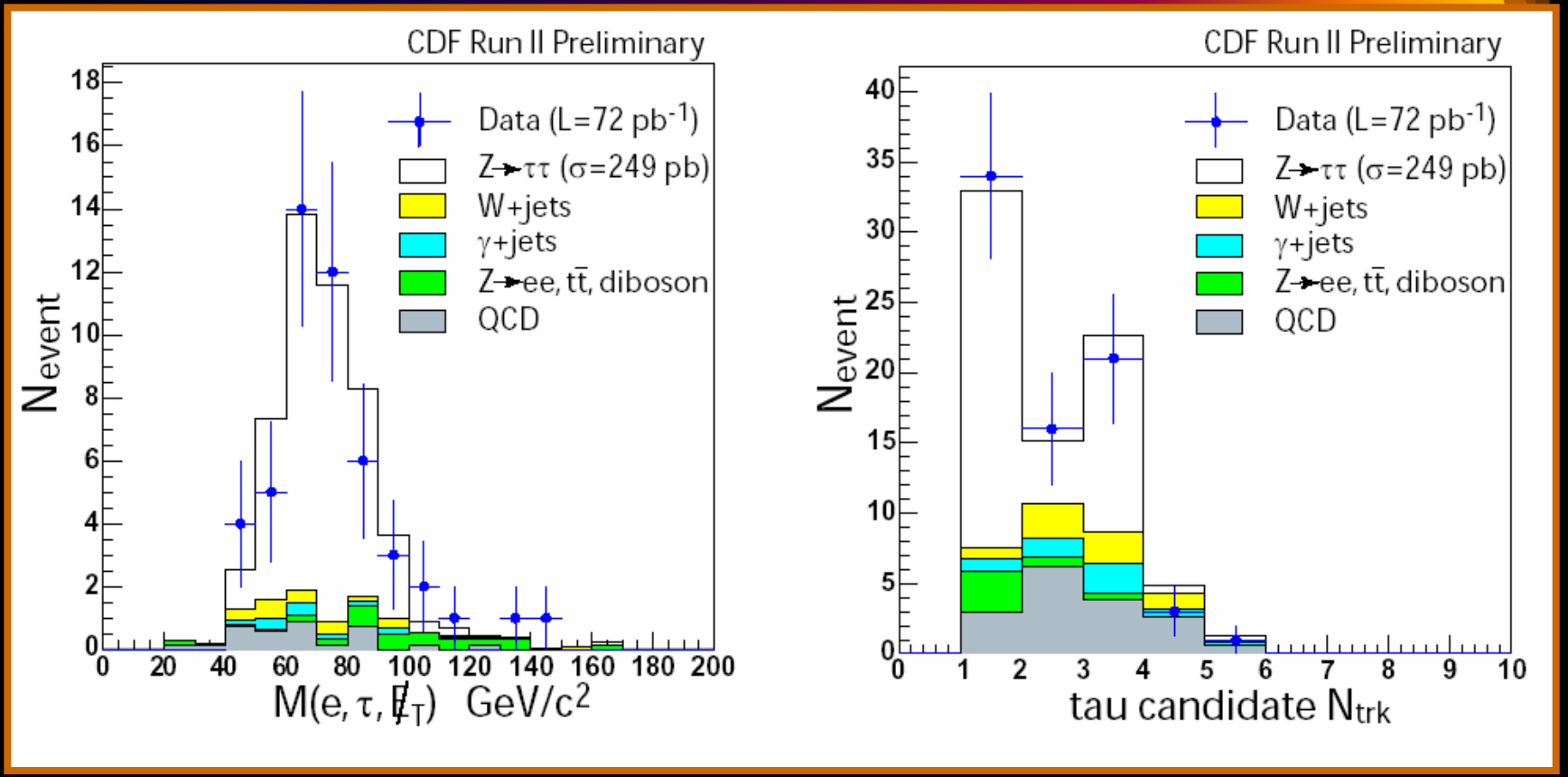
# Run II preliminary: $Z \rightarrow \tau_e \tau_h$ (I)




- Electron ET and Tau PT distributions for OS data

# Run II preliminary: $Z \rightarrow \tau_e \tau_h$ (II)



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# Run II preliminary: $Z \rightarrow \tau_e \tau_h$

## Data : 78 events

- $Z \rightarrow \tau_e \tau_h$: 39 events
- QCD: 28±14 events
- **Z→ee:** 3.7 events

A clear tau signal even before OS cut

## Data OS: 47 events

- $Z \rightarrow \tau_e \tau_h$ : 39 events
- QCD: 11±6 events
- $Z \rightarrow ee$: 2.8 events

# Status of


# analysis @ CDF II

## the muon channel

IFAE 2004 Torino, 14 Aprile 2004

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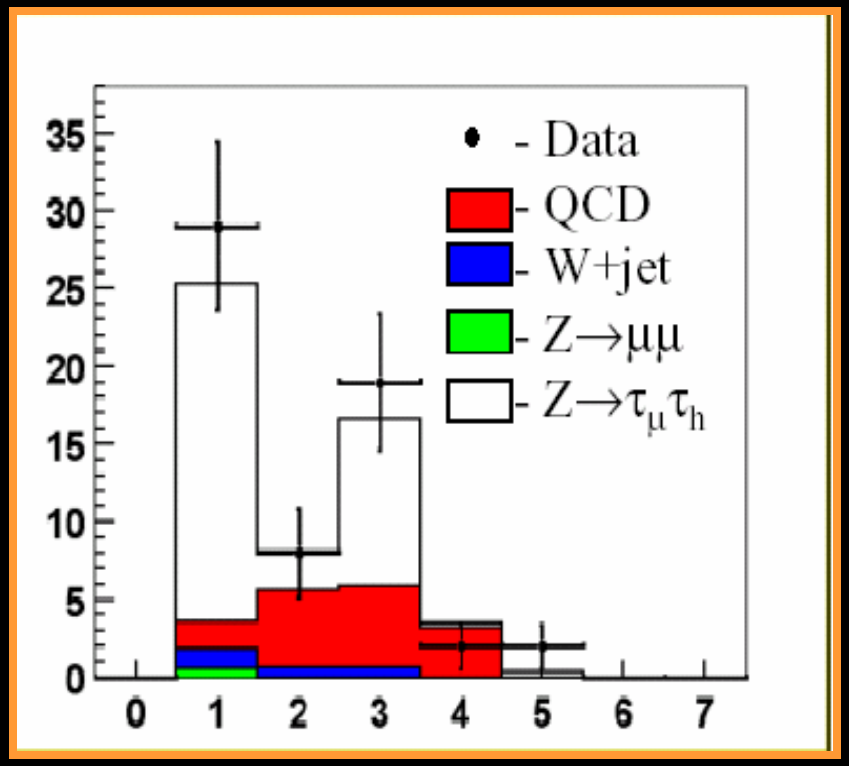
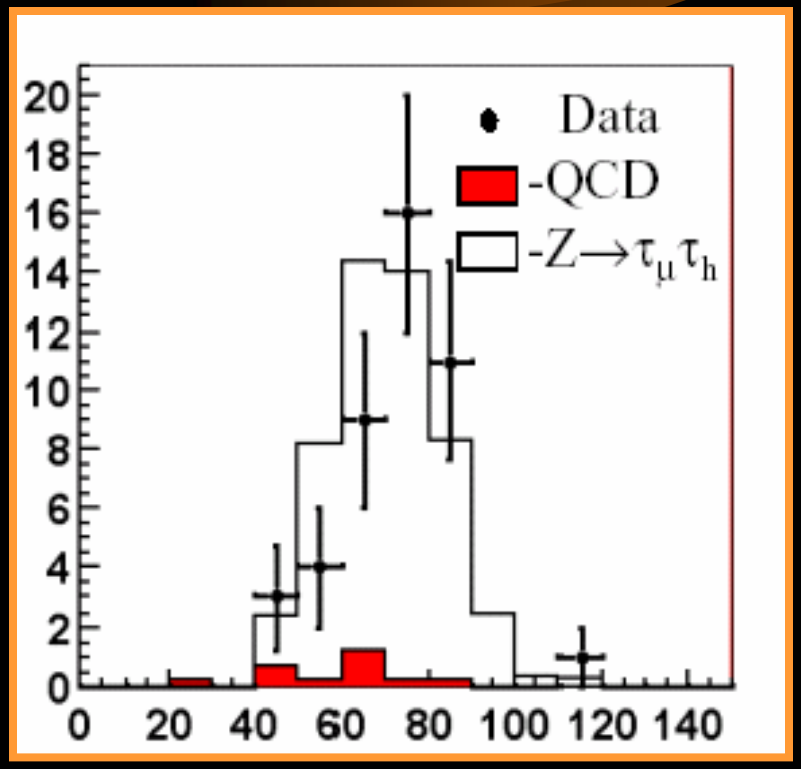
# $Z \rightarrow \tau_\mu \tau_h$ selection

- **$\mu$ selection**
  - CMUP or CMX muons
  - $P_T > 8.0$
  - $E_{EM} < 2.0$
  - $E_{HAD} < 6.0$
  - $|Z0| < 60$ cm
  - (3+3)×7 track quality
  - $\Delta X_{CMU} < 4$ cm, $\Delta X_{CMP} < 7$ cm
  - $\Delta X_{CMX} < 5$ cm
  - $d0_{CORRECTED} < 0.2$
  - TIso4 < 1
- **Event cuts**
  - 1 muon and 1 tau
  - no cosmics bit set
  - $|\Delta Z_{ij}| < 5$ cm
  - MET is corrected for the $\mu$
  - $P_T(\mu, MET) > 25$ GeV/c
  - $M_T(\mu, MET) < 25$ GeV/$c^2$
- **$\tau$ selection**
  - CdfTau object
  - $|\eta_{track}| < 1$
  - shrinking signal cone
  - Iso: no tracks > 1 GeV, $\pi^0 > 1$GeV
  - $P_T^{seed} > 6$ GeV/c
  - (3+3)×7 track quality
  - $d0_{CORRECTED}^{seed} < 0.2$
  - Iso4R < 0.15
  - $\xi < 0.1$
  - no $\mu$ stub behind
  - $M^{tracks+pi0} < 2.5$ GeV/$c^2$
  - $P_t^{track+\pi0} > 15$ GeV/c

# Run II preliminary: $Z \rightarrow \tau_\mu \tau_h$



# $Z \to \tau\tau_h$ cross-section measurement: Calibration for many Searches

$$\sigma\big|_{Z/\gamma^* \to \tau\tau} = \frac{1}{L} \frac{1}{2B(\tau \to e)B(\tau \to \tau_{had})} \times \frac{(N^{obs} - N^{background})}{\alpha \times \varepsilon^{e}_{ID}\varepsilon^{e}_{trig}\varepsilon^{e}_{Z} \times \varepsilon^{\tau}_{ID}\varepsilon^{\tau}_{trig}\varepsilon^{\tau}_{1,3-prong} \times \varepsilon_{event\ cuts}}$$



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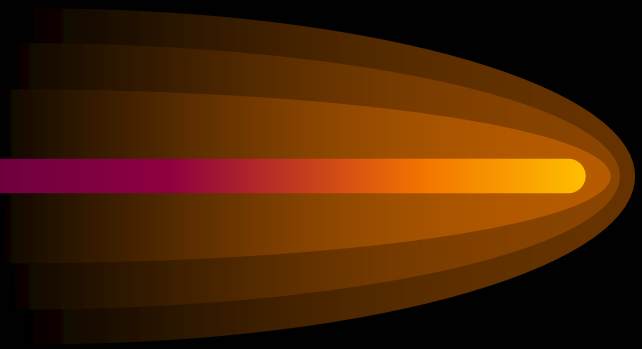
# what's next?

- Finish background estimate (WW, ...)
- Final systematic uncertainties for background subtraction
- PDF, ISR, FSR uncertainties
- Complete lepton ID efficiency measurement
- Increase data (~ +200 pb –1 )
- PRD ?

# Exotic Analysis in progress





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# Using Taus in: searches beyond SM

- chargino-neutralino production in mSUGRA and GMSB
- RPV scalar top decay (e, $\mu$ channels)
- $H^0 \rightarrow \tau\,\tau$
- LFV Higgs $H \rightarrow \mu\tau$

–MC samples
–Acceptance study
–Backgrounds
–Optimization of S/B



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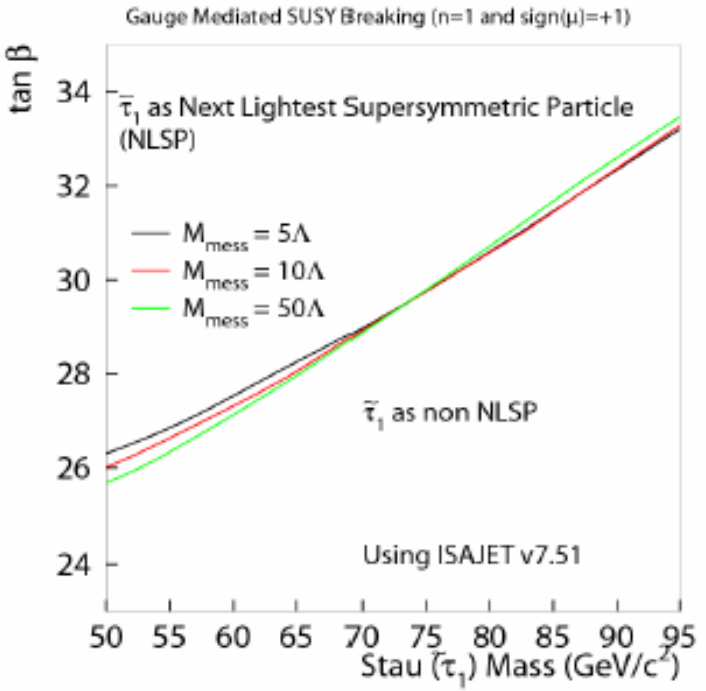
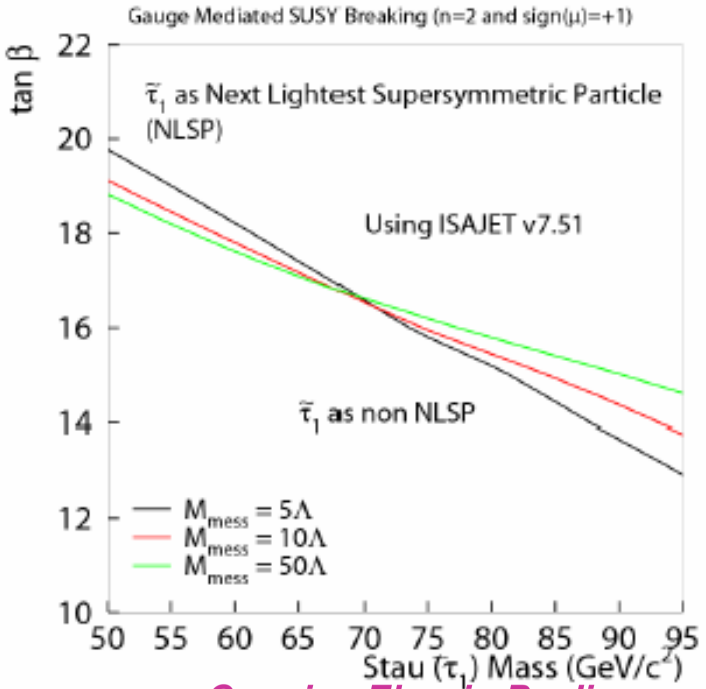
# GMSB SUSY

- In Gauge-Mediated SUSY Braking (GMSB) SUSY, for certain regions of the parameter space, especially large tanβ the lightest $\tilde{\tau}_1$ can be NLSP.
- Process under study is $p\bar{p} \rightarrow \tilde{\chi}^{\pm}_1 \tilde{\chi}^0_2$:
  - cross-section depends on GMSB parameters (mostly via $\tilde{\chi}^{\pm}_1 / \tilde{\chi}^0_2$ masses, which are ~ Λ)



# GMSB $\chi^{\pm}\chi^{0}$ Search with Taus

## Model

LSP: *G*

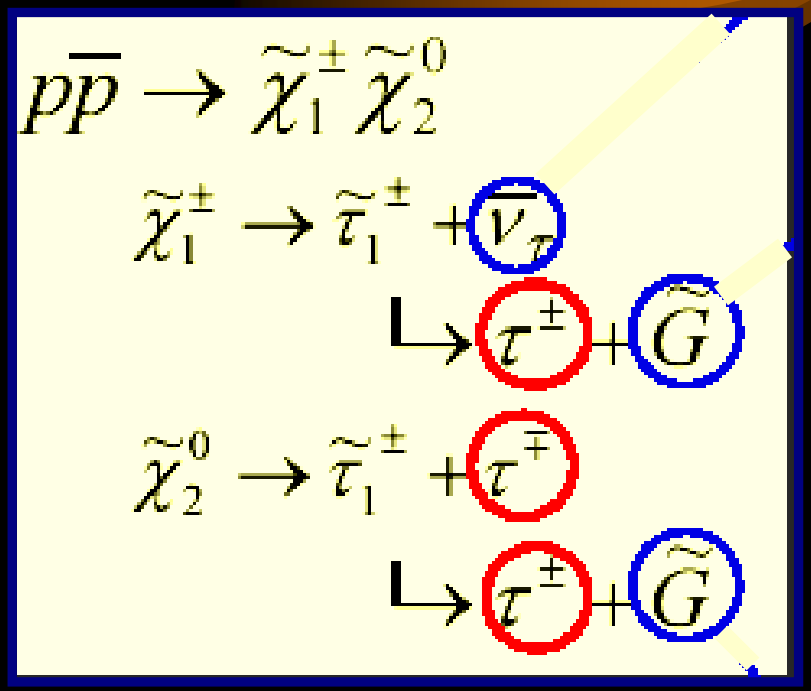
NLSP: $\tilde{\tau}_1$ ($\rightarrow\tau$+*G*)

**Signature: $3\tau+\not{E}_T$**

(Br~100%)

LEP:$m_{\tau}$= 86.9 GeV/$c^2$

$\sigma(pp\rightarrow\chi^{\pm}\chi^{0})$= 265 *fb*

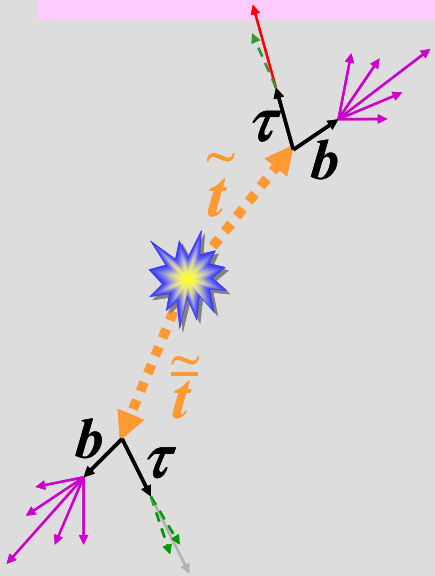



- Acceptance study ~ 4%
- Signal yield 2-8 events in 1 $fb^{-1}$

# RPV mSUGRA Stop Decays

- Stop pairs are produced thru RPC
- Assuming RPV only in the 3rd generation( $\lambda'_{333}$ in $\lambda'_{ijk} L^i Q^j \bar{D}^k$ ):

$$p\bar{p} \to \tilde{t}_1\bar{\tilde{t}}_1, (\tilde{t}_1 \to b\tau)$$
$$\to (bl\nu_l\bar{\nu}_\tau)(\bar{b}\,\tau_h)$$




$$\underbrace{l + \tau_h}_{\text{Trigger}} + \underbrace{b + b}_{\text{No } b\text{-tag for Run I}}$$

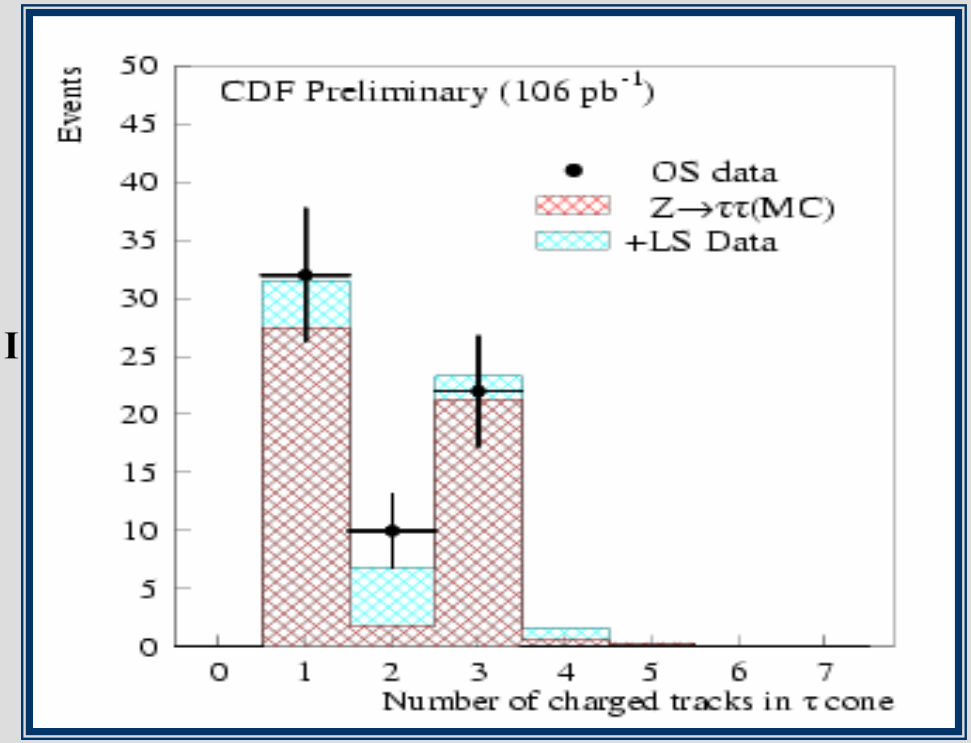
**Dominant SM BGs**

- $Z(\to \tau\tau)$ + ≥2 jets
- $W(\to l\nu)$ + ≥3 jets
- QCD
- $t\bar{t} \to Wb+Wb$
- $WW/WZ/ZZ$

## $\tau_h$ selection (106 pb$^{-1}$):

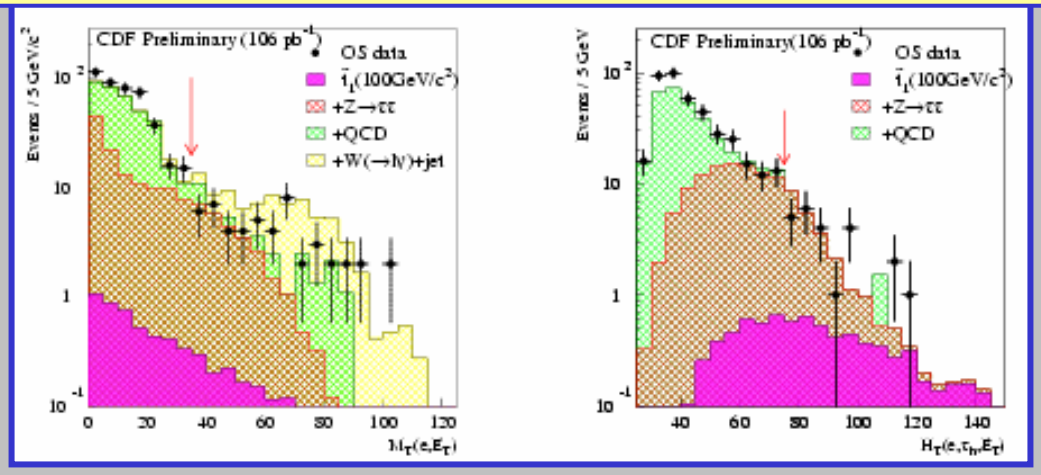
- $\tau_h$: cluster $P_T$>15 GeV/c, $|\eta|$<1.0

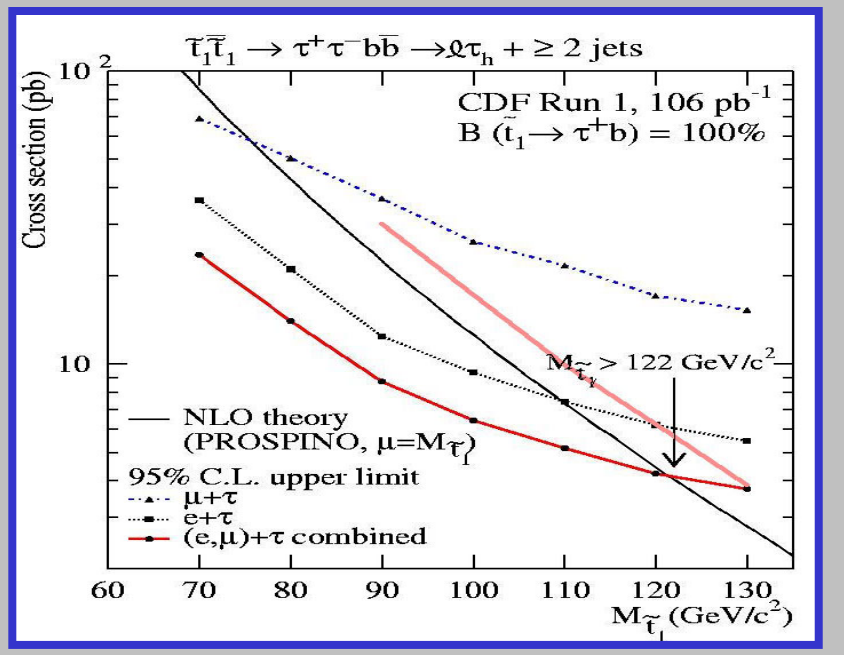
  $\tau_h$ ID: number of tracks and $\pi^0$ in a narrow cone, isolation energy, etc.



## Additional Selections:

$M_T$(lepton,$\not\!\!E_T$)< 35 GeV/$c^2$  $H_T$(lepton,$\tau_h$,$\not\!\!E_T$)> 70 GeV




≥ 2 jets: $E_T$ > 15 GeV

| channel | Background | Events |
|---|---|---|
| e | 1.92 ± 0.18 | 0 |
| μ | 1.13 ± 0.13 | 0 |

**ALEPH Limit:** $m_{\tilde{t}} > 93\ \mathrm{GeV/c^2}$

**Run II estimate for the Acceptance assuming $M_{stop}$= 100 GeV/$c^2$: 10-14 %**

# RPV scalar top decay

*Run II estimate for the Acceptance assuming $M_{stop}$ = 100 GeV/$c^2$: 10-14 %*

# Summary

- ✓ $Z \to \tau_e \tau_h$ – almost done
- ✓ $Z \to \tau_\mu \tau_h$ – almost done
- ✓ Most of preparatory work (efficiencies, optimization, MC production, background studies) is already done
- ✓ Several Exotic analysis with $\tau$(s) in the final state are under way
- ✓ 4 APS abstracts, 2 SUSY2004 from the Lepton + Track Trigger Data

# that's all Folks !