Tau Leptons at CDF

OUTLINE
- Why ?
- How ?
- Searches with taus at CDF
- Taus at ATLAS
- Conclusions

Experimental HEP Seminar
University of Pennsylvania
April 15th, 2008

Anadi Canepa
University of Pennsylvania
Taus in the SM and beyond

**Standard Model**
- $H \rightarrow \tau \tau \sim 10\%$ in low mass region

**Supersymmetry**
- Higgs sector
  - SM-like $h, H^\pm, H^{\pm\pm}$
  - RPV, $t_1 \rightarrow b\tau, s\nu \rightarrow \tau\ell$
  - At large $\tan\beta$,
    - mSUGRA $\chi_2^0 \rightarrow \tau\nu\chi_1^0$
    - GMSB $\tan\beta, \tau_1 \rightarrow \tau G$

**New gauge bosons**
- Sequential $Z'$
- LFV $Z'$
  - $Z' \rightarrow \tau\ell$

April 15th, 2008

Taus at CDF, A. Canepa
The tau lepton

- Short lived
  - Mean lifetime 291 ps
  - Decay length 87 μm
- \( m = 1.8 \text{ GeV} \)
- Rich phenomenology!

### Decay Modes

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Final Particles</th>
<th>BR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leptonic</td>
<td>( e^- \bar{e} \nu_\tau )</td>
<td>17.8%</td>
</tr>
<tr>
<td></td>
<td>( \mu^- \bar{\mu} \nu_\tau )</td>
<td>17.4%</td>
</tr>
<tr>
<td>Hadronic 1-prong</td>
<td>( \pi^- \nu_\tau )</td>
<td>11.1%</td>
</tr>
<tr>
<td></td>
<td>( \pi^- \pi^0 \nu_\tau )</td>
<td>25.4%</td>
</tr>
<tr>
<td></td>
<td>( \pi^- 2\pi^0 \nu_\tau )</td>
<td>9.2%</td>
</tr>
<tr>
<td></td>
<td>( \pi^- 3\pi^0 \nu_\tau )</td>
<td>1.1%</td>
</tr>
<tr>
<td></td>
<td>( K^- \nu_\tau )</td>
<td>0.7%</td>
</tr>
<tr>
<td></td>
<td>( K^- \pi^0 \nu_\tau )</td>
<td>0.5%</td>
</tr>
<tr>
<td>Hadronic 3-prong</td>
<td>( 2\pi^- \pi^+ \nu_\tau )</td>
<td>9.5%</td>
</tr>
<tr>
<td></td>
<td>( 2\pi^- \pi^0 \pi^0 \nu_\tau )</td>
<td>4.4%</td>
</tr>
</tbody>
</table>

**Tracks**
- \( \pi^\pm, K^\pm \)
- \( \pi^0 \)
- \( \pi^\pm, K^\pm \)
STEP 1 *Calorimeter cluster*
- “Clump” clustering
  - Seed (shoulder) tower $E > 6$ (1) GeV
  - $N$ towers $< 6$

STEP 2 *Track matching*
- Highest $p_T$ track pointing to the cluster in cone $R = R(\eta, \varphi) = 0.4$
- Seed track *becomes* tau direction

STEP 3 *Geometry*
- “Signal” and “Isolation” Tracks
  - $\alpha^{\text{sig}} \equiv \alpha(\varphi, \theta) < \min (0.17, 5/E_\tau)$
  - $0.17 < \alpha^{\text{iso}} < 0.52$
  - $p_T > 1$ GeV
Proportional strip/wire drift chamber
- 2 coordinates
- Located at $6\chi_0$ in CEM
- Position resolution 2-3 mm
- Energy resolution ~ 30%
- Clustering:
  - seed strip
  - cluster ±5 strips the seed
  - calculates $\chi^2$

Assumptions

CEM $E$ assigned to $\pi^0$
Reconstructed $\tau$ identified with
- Visible momentum $p_{\text{vis}} = p_{\text{tracks}} + p_{\pi^0}$

Reconstruction of neutral $\pi^0$ from showers in the CES detector
Tau identification at EWK scale

- Taus are reconstructed from
  - Narrow cluster in HAD calorimeter
  - Track pointing to it
  - Showers in the CES detector

~ 1/3 jets reconstructed as taus

Electrons reconstructed as taus

Identification criteria

- Vis. Mass < 1.8 GeV
- 1 or 3 signal tracks
- Isolation
  - track isolation
  - $\pi^0$ isolation
  - calorimeter isolation
- Electron suppression
  - Energy based cut
  - Explicit ID electron removal

Graph showing EM fraction vs E/p for hadronic tau and electron.
... at large E

- Energetic taus
  - collimated decay products
  - track resolution $\sigma(p_T)/p_T^2 = 0.0015$ GeV$^{-1}$

- Loosen up the requirements on tau candidate mass

- Calibration of CES detector
  - Position and energy device
    - now!
  - Visible momentum resolution:
    - 1-prong $\tau$ from 66% to 82%
    - 3-prong $\tau$ from 82% to 85%

Visible Mass (GeV) vs. Tau calorimeter E (GeV)

$m < m_{\text{max}} = f(E)$

$m < 1.8$ GeV

April 15th, 2008

Taut Leptons at CDF, A. Canep
Efficiency measurement

\[ \mathcal{E} = \frac{N^{ID}_{\text{real}}}{N^{ID}} \]

- MC measurement
  - Select \( \tau \) originating in \( W \rightarrow \tau \nu \)
- Data measurement
  - Taus are different from muons and electrons, no resonance!

**Three approaches**

- Normalization to \( W \rightarrow \tau \nu \)
  \[ \sigma = \frac{N^{\text{obs}} - N^{\text{bkg}}}{A \cdot L \cdot \mathcal{E}} \equiv 2.7 \text{ nb} \]
- Tau embedding
- Background from fit to data

\[ \mathcal{E} = \frac{N^{ID \tau} - N^{ID \text{backg}}}{N^{\tau} - N^{\text{backg}}} \]
Misidentification (fake) rates

- Jets faking taus
  - Fake rate \( FR = \frac{N^{ID}\tau}{N^{jet}} \)
  - Measured in data samples collected with jet triggers
    - If measured in MC samples, must tune the tau shape and hadronic response

- Electrons faking taus
  - Fake rate \( FR = \frac{N^{ID}\tau}{N^{ele}} \)
  - Measured in data
  - Select events in the Z mass window
    - One ID electron & One reconstructed tau
  - Subtract background from side-band
  - Fake rate \( \sim 10^{-3} \)
EWK Measurements
The W cross section

W's as the largest source of isolated taus
Best choice for understanding τs

Test of lepton universality!

Events selected if
τ Vis E_{T} > 25 GeV & MET > 30 GeV
τ back-to-back w.r.t. MET (no extra jets)

Acceptance ~ 1%

Backgrounds
QCD measured in QCD enriched independent sample

W→ev from fit to data

σ(pp-bar→W)·BR(W→τν) = 2.62 ± 0.07(stat) ± 0.21(syst) ± 0.16(lum) nb
The Z cross section

- Z as a “calibration” for a number of searches!
- Golden channel with one hadronic and one leptonic tau
- Events selected if
  - $\tau$ Vis $E_T > 10$ GeV & electron $E_T > 10$ GeV
  - Electron and tau with different charge (OS events)
  - Acceptance $\sim 5%$
- Dominant backgrounds from QCD
  - Jet $\rightarrow \tau$
  - Jet $\rightarrow e$
  - Flat electron isolation
    $\text{Nev}^{\text{LS}} = \text{Nev}^{\text{OS}}$
  - Jet $\rightarrow \tau$
    $\gamma \rightarrow e$
    Isolated electrons
    $\text{Nev}^{\text{LS}} = \text{Nev}^{\text{OS}}$
  - Jet $\rightarrow \tau$
    $W \rightarrow e\nu$
    $\text{Nev}^{\text{LS}} << \text{Nev}^{\text{OS}}$
**Backgrounds**

- QCD background suppressed asking for large $p_T$ and low $m_T(e, \text{MET})$
- Background estimate
  - QCD dijet
    - LS data events with non isolated electrons
  - $\gamma$+jet
    - LS data events with isolated electrons
  - $W$+jets MC based estimate
  - $Z/\gamma^* \rightarrow \text{ee}$ MC based estimate

\[
m_T = \sqrt{2 \cdot p_T^{\text{ele}} \cdot \text{MET} \cdot (1 - \cos \Delta \varphi)}
\]

\[
p_T = \sqrt{p_T^{\text{ele}} + \text{MET}}
\]
Results

- Signal extraction
  - 4 regions in $m_T(e, \text{MET})$ and electron isolation
  - split into OS and LS samples
  - Normalizations from fit to data

OS events

<table>
<thead>
<tr>
<th>$M_T$</th>
<th>$\text{W+jets}$</th>
<th>$\text{QCD}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>50:100 GeV</td>
<td>$\tau\tau$</td>
<td></td>
</tr>
<tr>
<td>0:50 GeV</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\text{Iso}$</th>
<th>$\text{Iso}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:1</td>
<td>2:8</td>
</tr>
</tbody>
</table>

$$\sigma(pp-\text{bar}\rightarrow Z) \cdot \text{BR}(Z\rightarrow \tau\tau) = 264 \pm 23 \text{ (stat)} \pm 13 \text{ (syst)} \pm 15 \text{ (lum)} \text{ pb}$$
3.2 fb$^{-1}$ on tape!

Record luminosity
$3.15 \cdot 10^{32}$ cm$^2$s$^{-1}$
MSSM Higgs sector with 2 doublets
- \( h, H \) (CP-even), \( A \) (CP-odd), \( H^\pm \)
  - \( h \) expected to be low mass
  - \( \tan \beta \) relevant parameter
- In the low mass region, \( h \) degenerate with \( A \), at large \( \tan \beta \)
- \( A \) cross section enhanced by \( \tan^2 \beta \)!

Higgs decays
- \( bb \sim 90\% \)
- \( \tau \tau \sim 10\% \)
Event selection

- Events selected in the sample used for the $Z \rightarrow \tau \tau$ cross section measurement
  - $\tau$ Vis $E_T > 15(20)$ GeV & lepton $E_T > 10$ GeV
  - new channel, $\tau_e \tau_\mu$

- Backgrounds
  - $W +$jets
    - Suppressed with $\zeta$ cut
  - Soft QCD
    - Suppressed with $H_T$ cut
  - Remaining QCD background
    - $\tau_e \tau_\mu$ channel, from events with non-isolated leptons
    - $\tau_h$ channels, computed from fake rate parameterization
  - $Z \rightarrow ll$ estimated from MC
Results

- Search acceptance $A(m_h=100 \text{ GeV}) \sim 1\%$
- No excess w.r.t SM predictions

Likelihood fit to the vis. mass to set limits
- three final states as separate channels
- backgrounds subject to gaussian constraints

Reach extends below $\tan\beta \sim 50$
for $m_A$ in $[120;160] \text{ GeV}$
The Higgs boson is crucial for confirming the SM!
- expected to be low mass (< 180 GeV)
- in the low mass region, BR (H→ ττ) ~ 10%
- recover acceptance letting W and Z to decay hadronically
  - W →lv (22%), Z →ll (6%), Z →νν (20%)
  - W →jj (67%), Z →jj(70%)

Search for WH, ZH, VBF H→ ττ, and gg fusion in events with two taus and two jets

One hadronic and one leptonic tau!
Event selection

Events selected if
- $\tau$ Vis $E_T > 15$ GeV & lepton $E_T > 10$ GeV
- Two jets with corrected $E_T > 15$ GeV
- Veto Z and accept events with OS leptons
- Acceptance $A(m=110$ GeV) $\sim 5\%$

Backgrounds
- Diboson, t-tbar, Drell-Yan from MC
- QCD (dijet, $\gamma$+jet,W+jet) from LS data
  - Correcting for DY contribution and W+jet charge correlation
  - $Z\to\tau\tau$ cross section measurement for validation of background model

<table>
<thead>
<tr>
<th>$2fb^{-1}$</th>
<th>$M_H=110$</th>
<th>$M_H=115$</th>
<th>$M_H=120$</th>
<th>$M_H=130$</th>
<th>$M_H=140$</th>
<th>$M_H=150$</th>
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<tbody>
<tr>
<td>WH</td>
<td>0.25(1.5%)</td>
<td>0.21(1.5%)</td>
<td>0.18(1.6%)</td>
<td>0.11(1.7%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZH</td>
<td>0.16(1.5%)</td>
<td>0.14(1.6%)</td>
<td>0.11(1.6%)</td>
<td>0.07(1.8%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VBF</td>
<td>0.14(1.4%)</td>
<td>0.13(1.4%)</td>
<td>0.12(1.5%)</td>
<td>0.09(1.6%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ggH</td>
<td>0.28(0.18%)</td>
<td>0.28(0.21%)</td>
<td>0.26(0.24%)</td>
<td>0.18(0.26%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.83±0.01</td>
<td>0.76±0.01</td>
<td>0.67±0.01</td>
<td>0.45±0.004</td>
<td>0.26±0.002</td>
<td>0.12±0.001</td>
</tr>
</tbody>
</table>
Results

- Train NN for mixed Higgs signal vs
  - Z→ττ (25% of background, ττ peak)
  - t-tbar (5% of background, Q²)
  - QCD (60% of background, energy range)
- Input 16 variables, rank with iterative method
- 3 NN scores per event, choose the min. one
- No excess w.r.t SM background

![Graphs and plots related to Higgs mass and CMS results.]

**KS prob = 68.4%**

**Observed (L = 2.0 fb⁻¹)**

- Jet → τ (QCD+Wjets)
- Top
- Diboson/Z → ll
- Z → ττ + jets
- Higgs(M_H = 120)-30

**L = 2.0 fb⁻¹**

**95% CL Limit/SM**

**Higgs Mass (GeV/c²)**
More exotic Higgs
Double charged SUSY Higgs

- Left-Right Symmetric Model (LRSM)
  - Right handed weak force
  - Mechanism for generating neutrino masses

- Higgs sector with 3 new triplets
  - 10 scalar bosons, among which $H_{R/L}^{++/-/-}$

- $\Gamma_{ll'} \sim h_{ll'}^2 m_H$
- Yukawa $h_{ll'}$ give mass to neutrinos
  - $h_{\tau}$ expected to be large!

CDF Exclusion Limits:
$m(H_{L}^{++/-/-}) > 112$ (114) GeV
$m(H_{R}^{++/-/-}) > 127$ GeV

CDF Run II Preliminary ($L=350$ pb$^{-1}$)

- $m(H_{R}^{++}) > 97$ GeV/c$^2$ (LEP 2)
- $m(H_{L}^{++}) > 99$ GeV/c$^2$ (LEP 2)

CDF 95% C.L. upper limit:
- $BR(H^{++} \rightarrow \mu^+\mu^-)=100\%$
- $BR(H^{++} \rightarrow e^+e^-)=100\%$

Exclusion Limits:
$m(H_{L}^{++/-/-}) > 150$ GeV
$m(H_{R}^{++/-/-}) > 127$ GeV

L = 1.1 fb$^{-1}$
Charged Higgs

- In the MSSM, $H^\pm$ could be lighter than the top
- $H^\pm$ from $t \rightarrow b H^+$
  - accessible at Tevatron!
- probing $m_H < m_t - m_b$
- Top BR's modified
- Different topologies in $W^\pm$ and $H^\pm$ decays

April 15th, 2008

$H^+$ decays to

$\tau \nu$
$cs$
$t \bar{b}$
$W^+ h^0$
$W^+ A^0$

Branching ratio

$H^+$ decays to

$\tau \nu$
$cs$
$t \bar{b}$
$W^+ h^0$
$W^+ A^0$

CDF Run II Preliminary

Excluded 95% CL

$\mu = 175$ GeV/c$^2$

$|t \bar{t}| = 192$ pb$^{-1}$

$BR(H \rightarrow t \bar{t}) = 1$; $BR(H \rightarrow t \bar{t} \bar{b}) = BR(H \rightarrow t \bar{t} \bar{b}) = BR(H \rightarrow W^+ H^-) = 0$

Tau Leptons at CDF, A.C.
New particles

- In the MSSM, the lightest stop ($t_1$) can be very light (large tan$\beta$ scenarios)
- Lighter than SM top!
- Decay into $\tau b$

New gauge bosons
- $Z'$, ED, ...

Is the third generation special?
State of the art

- Tau reconstruction seeded from calorimeter cell or charged track
  - Energy flow for soft taus (from 20 to 70 GeV)
- Calorimeter based isolation, cluster shape and track multiplicity
  - Radius of EM jet
  - Isolation $E_{T}^{EM}/E_{T}^{HAD}$
    - $0.1 < \Delta R < 0.2$ for $E > 70$ GeV
    - $0.2 < \Delta R < 0.4$ for soft taus
  - Impact parameter
  - Cut based or multivariate classification
- Misidentification rate as a function of
  - jet type (quark or gluon)
  - energy and $\eta$

April 15th, 2008

Tau Leptons at CDF, A. Canepa

27
Higgs searches

Tau Leptons at CDF, A. Canepa

[Graphs and diagrams showing Higgs search results and signal significance]

- VBF production with $H \rightarrow \tau\tau$
- Forward jets
- Collinear approximation

April 15th, 2008

Tau Leptons at CDF
Conclusions

- The tau lepton was discovered in the late ‘70
- Electroweak processes involving taus are now measured precisely
  - *CDF (and D0) established robust tools for identifying hadronically decaying taus at hadron collider*
- *Taus provide insights into EWK symmetry breaking*
- Taus are excellent probes for New Physics!
  - *Abundance of taus in SUSY, L-R symmetric models, theories with new gauge bosons, etc*
  - *Just limits, so far*
  - *But more data to come at Tevatron …*

Where is the Higgs boson?

And a new era at the LHC!
W at CDF

- Electron rejection 90%
- Visible mass 85%

QCD
- Use events in L3_PS100_L1_MET25
- Select only events with taus 0.1<EMF<0.9 → assume flat distribution of EMF for jets

W decaying into electron+neutrino
- Low fake rate, we cannot use only MC because of large uncert
- Background if real ele emitted photons and not ID as electron -> use the photon shower information
- Take W into tau candidates with EMF > 0.9 (likely ele), plot $\Delta Z$(track,CES) in Wtau MC and Wele MC. Use as template, fit to data, find the background

SYSTEMATICS
- Tau ID 4.5% stat + 2.8 sys
- PDF 2%, monojet cut 2.6%
Z at CDF

Extract the signal:

- we now fit the expected number of events to the observations in all regions simultaneously and extract all the normalizations

<table>
<thead>
<tr>
<th>SYSTEMATICS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometrical and kinematic acceptance (incl. PDFs) 3.0</td>
</tr>
<tr>
<td>Electron ID 1.9</td>
</tr>
<tr>
<td>Tau ID 3.0</td>
</tr>
<tr>
<td>Electron Trigger Efficiency 1.0</td>
</tr>
<tr>
<td>Tau Trigger Efficiency 1.0</td>
</tr>
<tr>
<td>Topology cuts 0.4</td>
</tr>
<tr>
<td>Background estimation 1.3</td>
</tr>
<tr>
<td>Total: 5.0</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>M_T 50:100 GeV</th>
<th>W+jets</th>
<th>QCD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M_T 0:50 GeV</td>
<td>QCD</td>
<td>QCD</td>
</tr>
<tr>
<td>Iso 0:1</td>
<td>Iso 2:8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
BACKGROUND
SYSTEMATIC UNCERTAINTIES (%)
Ele ID 2
Muon ID 3
Tau ID 3
Trigger 0.3-1
Fake background in emu channel 32
Fake background in tau channels 6-9
Theory cross section 2-13
PDF 6
In the MSSM, the masses and couplings of the Higgs bosons depend on $\tan\beta$ and $m_A$ at tree level. Radiative corrections introduce additional dependencies on SUSY parameters. In a constrained model, where unification of the SU(2) and U(1) gaugino masses is assumed, the most relevant parameters are the mixing parameter $X_t$; the mass parameter $M_2$; the gluino mass $m_{\tilde{g}}$; the common scalar mass $M_{\text{SUSY}}$.

In this analysis, the $m_{\text{max}}$ h and no-mixing scenarios are studied. The scenarios have the following parameters:

- **$m_{\text{max}}$ h scenario:**
  - $X_t = 2$ TeV;
  - $M_2 = 0.2$ TeV;
  - $m_{\tilde{g}} = 0.8$ TeV;
  - $M_{\text{SUSY}} = 1$ TeV.

- **No-mixing scenario:**
  - $X_t = 0$ TeV;
  - $M_2 = 0.2$ TeV;
  - $m_{\tilde{g}} = 1.6$ TeV;
  - $M_{\text{SUSY}} = 2$ TeV.
BACKGROUND
SYSTEMATIC UNCERTAINTIES (%)
Trigger 0.3-3
Ele ID 2
Muon ID 3
Tau ID 3
JES 16
MC stat 0.5
Normalization 2
MC model 20
Tau sneutrino (I)

- Lepton number violation observed in the neutral sector
- RPV terms added to the theory

**Search for \( \tau \)-sneutrino**
- “Single coupling dominance”
  - \( \lambda_{311} \neq 0 \) and \( \lambda_{132} \neq 0 \)
- Look for “bump” in \( M_{e\mu} \)
  - Muon \( p_T > 25 \text{ GeV/c} \)
  - Electron \( E_T > 30 \text{ GeV} \)
- SM Background
  - Drell-Yan, diboson, t-tbar

**What if \( R_P \) is violated?**

\[
W_{RPV} = \frac{1}{2} \varepsilon_{ab} \lambda_{ijk} L_i^a L_j^b E_k^c + \varepsilon_{ab} \lambda'_{ijk} L_i^a Q_j^b D_k^c + \ldots
\]

- SM suppressed vetoing
  - events with same flavor leptons
  - events with MET > 15 GeV not aligned with muons or with more than one jet \( E_T > 30 \text{ GeV} \)
 Tau sneutrino (II)

**arXiv:0711.3207**

<table>
<thead>
<tr>
<th>SM Backgr.</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z/\gamma^* \rightarrow \tau\tau$</td>
<td>42.9±4.2</td>
</tr>
<tr>
<td>WW</td>
<td>13.7±1.5</td>
</tr>
<tr>
<td>t-tbar</td>
<td>1.4±0.3</td>
</tr>
<tr>
<td>WZ</td>
<td>1.2±0.2</td>
</tr>
<tr>
<td>Total Backg.</td>
<td>59.2±5.3</td>
</tr>
<tr>
<td>Data</td>
<td>68</td>
</tr>
</tbody>
</table>
ATLAS SM H in VBF (10/fb)
Acceptance x Efficiency

CDF Run II Preliminary

- electrons (default)
- electons (improved)
- muons (default)
- $\nu_\tau$'s (default)
- $\nu_\tau$'s (improved)

Acceptance x ID Efficiency for Leptons

$\tilde{\nu}_\tau$ Mass (GeV/c$^2$)
Tau triggers

Dataflow of CDF "Deadtimeless" Trigger and DAQ

- Custom designed hardware
- Tracking, calorimeter towers, MET
- Primitives shared by other paths

- Custom hardware & commodity processor
- Calorimeter clustering, track isolation, MET
- Bandwidth limitations

- Processor farm
- Full event reconstruction

L1 output < 30 kHz
L2 output < 1 kHz
L3 output < 150 Hz
L2 Tau triggers

- **TAUMET**
  - MET > 20
  - Narrow isolated jet E > 10 GeV
- **DITAU**
  - Two narrow isolated jets E > 10 GeV
- **ELECTRON & TRACK**
  - Central electron E > 8 GeV
  - Isolated track $p_T > 5$ GeV
- **MUON & TRACK**
  - Central muon $p_T > 8$ GeV
  - Isolated track $p_T > 5$ GeV

\[
R = \sigma \cdot L_{\text{inst}}
\]

\[
R \left(100 \cdot \text{E30cm}^2\text{s}^{-1}\right) = 14 \times 100 / 1000 = 1.4 \text{ Hz}
\]
New bosons

- New physics predicts new gauge bosons
  - \( Z' \), RPV SUSY, ED, ....

- Events with
  - \( \tau \) Vis \( E_T > 15 \text{ GeV} \)
  - lepton \( E_T > 10 \text{ GeV} \)

Background reduced with MET cut

Observed: 4
Background: \( 2.8 \pm 0.5 \)

Vector Boson, SM couplings
- \( m(Z') > 399 \text{ GeV} \)
- Scalar Boson, \( sv, A'B = 0.01 \)
- \( m(sv) > 377 \text{ GeV} \)
Double Charged H

- Events collected via LEPTON&TRACK trigger
  - $\tau$ Vis $E_T > 15$ GeV & lepton $E_T > 20$ GeV
  - Split into 2 exclusive channels
    - $\geq 1$ isolated lepton candidate with $E_T > 8$ GeV
  - Loose cuts yield large acceptance!

- Signal extraction
  - $30 < m$ (like sign pair) $< 125$ GeV
  - $H_T > 190$ GeV in thee lepton channel
  - $H_T > 120$ (150) GeV in four lepton channel

- Backgrounds
  - QCD, cosmics, $W+$jets, Drell-Yan+jets
    - Measured in data events with non-isolated leptons
  - Diboson and $t$-$\bar{t}$ from MC
  - validated in control regions with non-isolated leptons and in low $H_T$ region

<table>
<thead>
<tr>
<th>Isolated Track</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass $&lt; 1.8$ GeV</td>
</tr>
<tr>
<td>track isolation</td>
</tr>
<tr>
<td>$\pi^0$ isolation</td>
</tr>
<tr>
<td>1 or 3 signal tracks</td>
</tr>
</tbody>
</table>

Background from mis-measured tracks might contaminate signal region.  
Highest $p_T$ track:  
$\sigma$(curv)$\leq 3 \times 10^{-6}$ (silicon tracks)  
$\sigma$(curv)$\leq 7 \times 10^{-6}$ (COT tracks)

<table>
<thead>
<tr>
<th>3 lepton channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZZ : 0.02</td>
</tr>
<tr>
<td>WZ: 0.09</td>
</tr>
<tr>
<td>Drell-Yan: 0.10</td>
</tr>
<tr>
<td>tt-bar: 0.06</td>
</tr>
<tr>
<td>$H^{+/−}(m=100$GeV$): 1.8$</td>
</tr>
</tbody>
</table>