Identification of τ Leptons at The DØ Experiment

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on behalf of **The DØ Collaboration**

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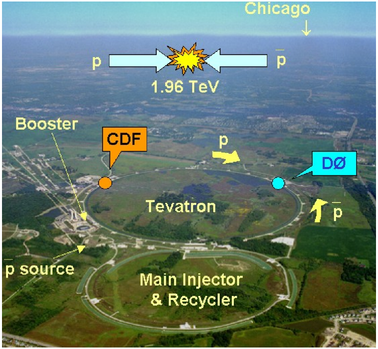
The 11th International Workshop on Tau Lepton Physics

Manchester, UK – 16th of September 2010

The Tevatron

Fermilab collider :

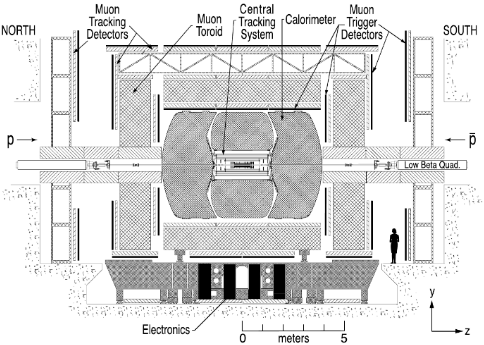
- $p\bar{p}$ collisions
- $\sqrt{s} = 1.96$ TeV
- $\mathcal{L}_{max} \sim 400 \times 10^{30}$ $cm^{-2}.s^{-1}$
- $8fb^{-1}$of delivered collisions
  $\sim$ 6 millions Z bosons into leptons



Two interaction points with detectors
CDF & DØ

The DØ detector

Multi purpose detector :
electrons, muons, taus, photons ID, (b-)jets, mET



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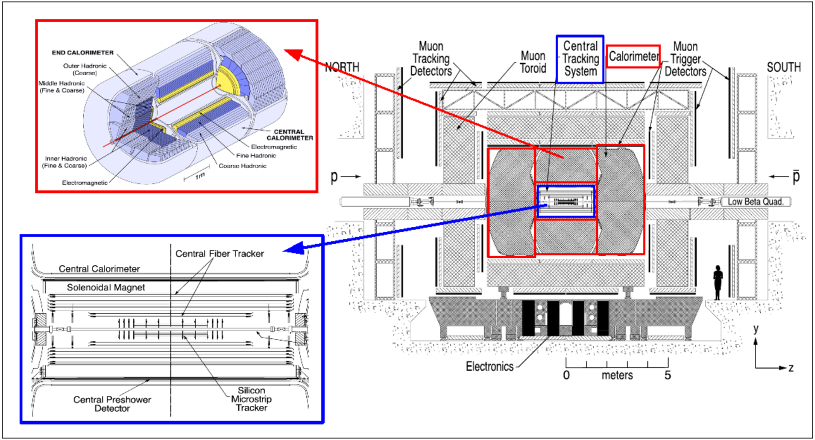

Why τ at hadron colliders ?

Potential acceptance gain for leptonic final states :
$(e, \mu) \Rightarrow (e, \mu, \tau)$: single lepton $\times 1.5$, dilepton $\times 2.0$, trilepton $\times 3.0$

- **Electroweak physics :** Test of lepton universality with $Z \to \tau\tau$ and $W \to \tau\nu_\tau$ cross section measurement.
- **Top quark physics :** top quark property measurements in τ final state are sensitive to new physics and test the Standard Model (SM) consistency.
- **Higgs searches :** Many decay chains initiated by Higgs boson (Electroweak Symmetry breaking origin) involve τ leptons and allow to increase the sensitivity.
- **New physics :** Supersymmetric extensions of SM predict new particles that can decay in τ leptons. τ final state acts as a probe of new physics.

... But experimentally challenging !

Impact of neutrino(s) involved in τ decay :

1. Invisible energy : ν escapes the detector without interaction.
2. Visible decay products are soft : more sensitive to backgrounds from soft QCD processes.

Impact of various τ decay modes :

1. **leptonic decays** ($\sim 35\%$) are indistinguishables from e/μ leptons produced in W/Z direct decays which are much more abundant and suffer from poor stat. ($\mathcal{BR}(\tau\tau \to e\mu) = 6\%$).
2. **hadronic decays** ($\sim 65\%$) :
   1. different signatures depending on the hadronic final state.
   2. Large bkg from direct QCD interactions in hadronic collisions.
3. Need to combine several channels.

Hadronically decaying τ leptons require sophisticated algorithms to deal with all these difficulties.

Overview

1. **τ reconstruction at DØ**
   - Tracks and calorimeter of τ object
   - τ candidate definition
   - Reconstruction efficiencies
2. **τ/jet discrimination**
   - Problematics and strategy
   - Algorithm performances
   - Further optimizations
3. **Energy measurement**
   - Problematics
   - Strategy : track propagation
     - Absolute correction
     - Relative correction
4. **Conclusions and outlooks**

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Tracks and calorimeter objects of τ_{cand}

Calorimeter cluster :
found by `Simple Cone Algorithm` in a $\Delta R \leq 0.5$ cone.

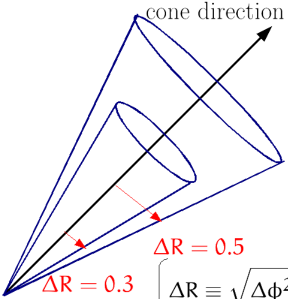
CAL clu

Electromagnetic subcluster :
found by `Nearest Neighbour Algorithm` with seed in the 3rd EM layer (finer segmentation). $E_{EMsubclu} \geq 800$ MeV.

EM sub clu

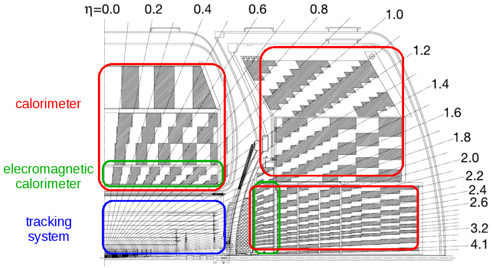
Tracks :
All tracks in a $\Delta R \leq 0.3$ cone around the cal cluster compatible with τ decay (inv. mass cut).
Highest track $p_T \geq 1.5$ GeV.

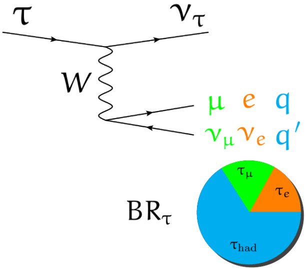
trk(s)



$$\begin{cases} \Delta R \equiv \sqrt{\Delta\phi^2 + \Delta\eta^2} \\ \eta \equiv -\frac{1}{2}\ln(\tan(\theta/2)) \end{cases}$$

Type of τ candidate





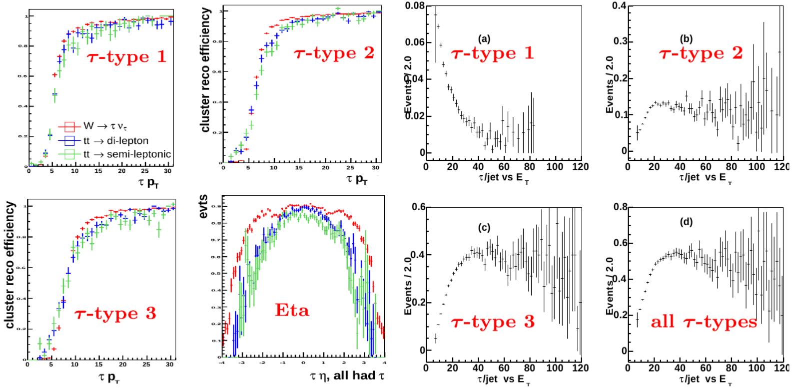
We will focus on **hadronic decay of τ** : τ_{had}

Reconstruction and DØ τ type definition for <u>hadronic</u> decay :

- DØ type 1 ≡ 1 trk , CAL clu $\sim \tau^{\pm} \to \pi^{\pm}\nu_{\tau}$
- DØ type 2 ≡ 1 trk , CAL clu, EM sub clu $\sim \tau^{\pm} \to \rho^{\pm}(\to \pi^{0}\pi^{\pm})\nu_{\tau}$
- DØ type 3 ≡ ≥ 2 trks, CAL clu $\sim \tau^{\pm} \to a_1^{\pm}(\to 3\pi^{\pm})\nu_{\tau}$

Reconstruction efficiencies

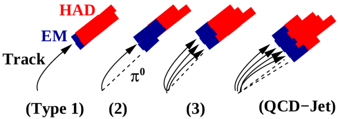
True τ (MC) **τ_{cand} from QCD evts (data)**



A large fraction of QCD objects (jets) can pass τ_{cand} reconstruction.

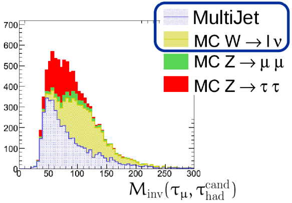
Overview

Identification of true τ



τ_{had} ≈ narrower jet with lower track multiplicities

Jets could have the same experimental signature as hadronic τ and have to be removed.



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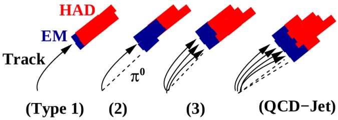

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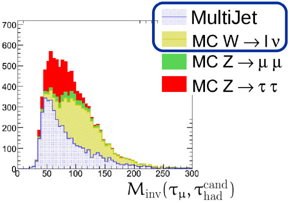
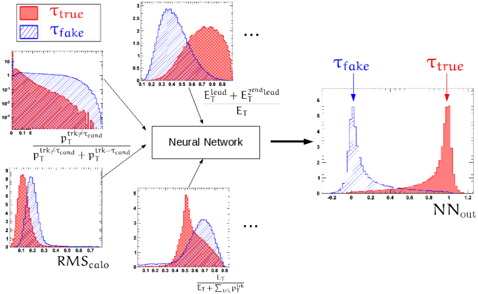


τ/jet separation

Several observables having different shape for true τ and jets are combined in a **Neural Network (NN)**.

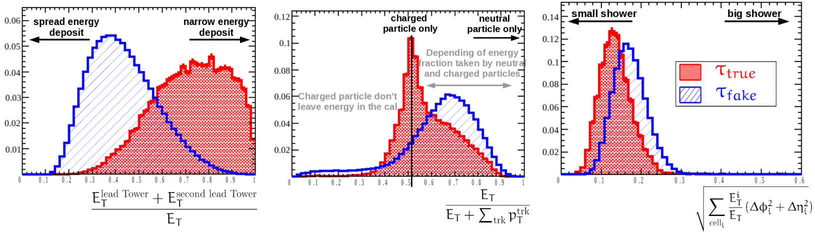


Discriminating observables

Which observables ?

- Isolation in the tracking system
- Isolation in the calorimeter
- Shower shape variables
- Correlations between tracks and calorimeter objects

Example of input variables and their physical meaning :



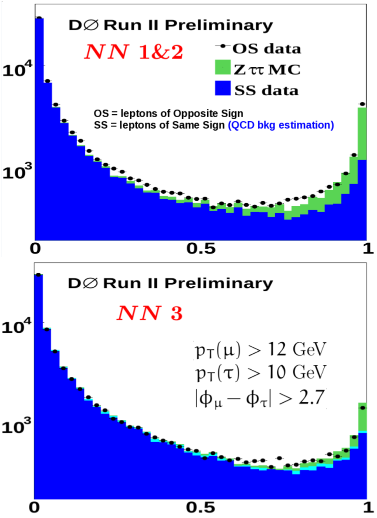
$Z \to \tau\tau$ events

Efficiencies (%)

$20 < E_T^\tau < 40$ GeV, $|\eta^\tau| < 2.5$

τ-type	1	2	3	all
jets	2	12	38	52
τ	11	60	24	95
$NN > 0.9$				
jets	0.06	0.24	0.80	1.1
τ	7	44	16	67

Data in $\mu\tau$ final state :



$W \to \tau\nu$ events

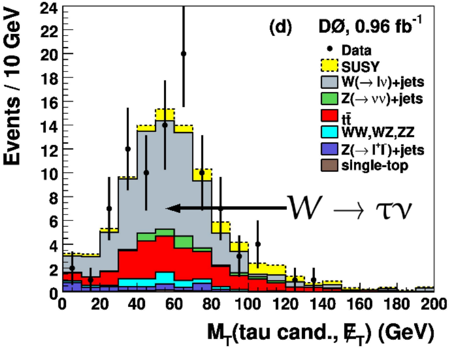
Context of search for new physics :

e.g. search for squark production in τ + 2jets+mET events.

$W \to \tau\nu \equiv$ SM background

Main event selection

- mET$\geq$ 75 GeV
- $p_T(j_i) \geq 35$ GeV
- $p_T(\tau) \geq 35$ GeV
- $\Delta R(j_i, \tau) \geq 0.5$



Phys. Lett. B 680 , 24-33 (2009)

Overview

Optimization strategy

General point of view : Neural Network output $\eta^{\text{NN}}(\vec{X})$ **converges** to

$$\eta^{\text{true}}(\vec{X}) \equiv \frac{\mathcal{S}(\vec{X})}{\mathcal{S}(\vec{X}) + \mathcal{B}(\vec{X})}$$

where $\vec{X} \equiv (x_1, x_2, ..., x_n)$ describes the discriminating variables space.

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In the τ identification context :

A lot of ideas were tested to optimize the identification of τ leptons :

- Include preshower detector measurement ✗
- Exploit the long τ life time (like for b-jets) ✓

} improve $\eta^{true}(\vec{X})$

- Tune NN parameters (epoch, nodes, statistics) ✓
- Dedicated training for τ of high p_T ✓
- Dedicated training for high luminosity events ✗

} minimize $|\eta^{NN} - \eta^{true}|$

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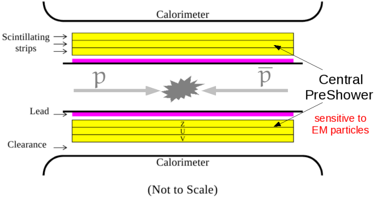
Central PreShower (CPS) for type 2

Physical idea. Exploit specific resonance of τ **type** 2 decay : $\tau^\pm \to \rho^\pm\nu \to \pi^\pm\pi^0\nu$. Use Central PreShower detector with fine segmentation : $\Delta\phi_{CPS} \simeq 0.1 \times \Delta\phi_{calo}$

$$\mathrm{CPS}_{\mathrm{cluster}} \approx \pi^0 \ ,\ \mathrm{trk} \approx \pi^\pm$$



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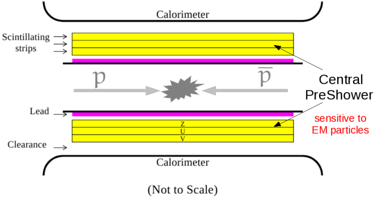

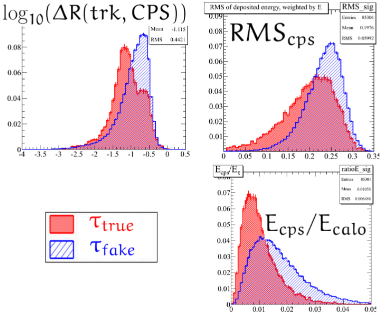

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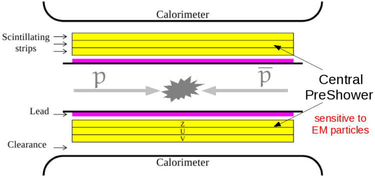
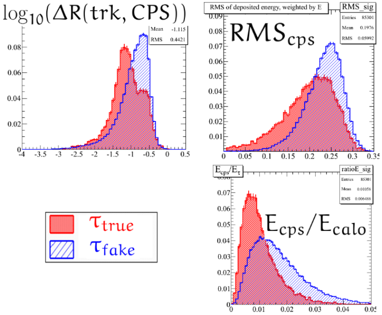


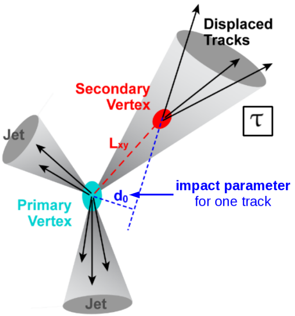
(Not to Scale)



After adding these variables in the NN **No significant improvement** was observed.

Reason : these informations were already included via calorimeter measurement.

τ is a long lived particle



Use impact parameter to remove
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(large $c\tau_{\text{life}} \Rightarrow$ large d_0)

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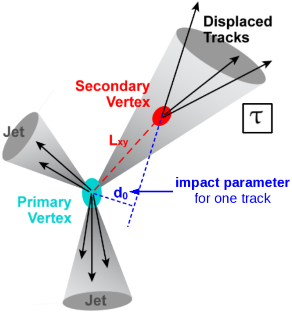

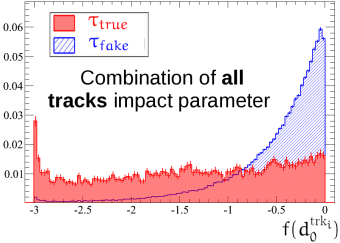

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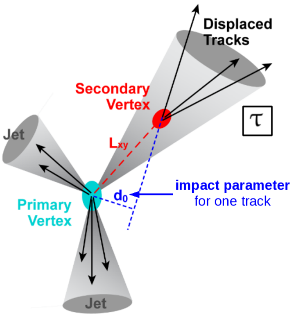

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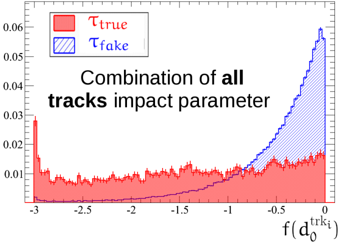

After adding these variables in the NN **clear improvement** was observed :
$\sim$ 10% more signal for the same bkg

Impact of optimizations

Consequences of optimizations : comparison of $S/B(p_T^{\tau_{cand}})$ after a cut

1. on NN[whitout opt.] (old NN)
2. on NN[with opt.] (new NN)
3. ratio of new/old

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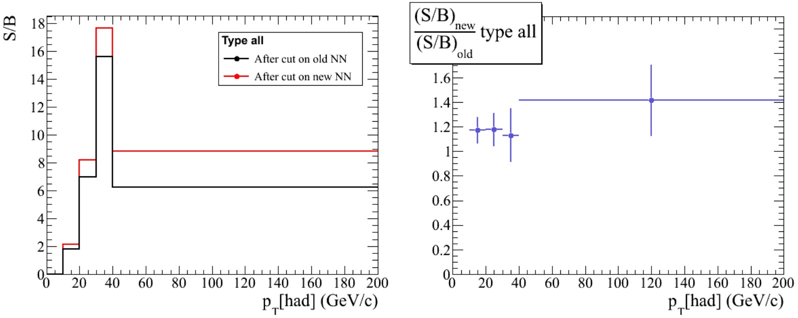

Optimizations bring $\sim 15\%$ improvement on $N(\tau_{true})/N(\tau_{fake})$ ratio

Overview

Why the E_τ measurement is tricky ?

Challenges of τ energy calibration from $Z \to \tau\tau$:

- Z peak suffers from escaping ν's energy : broad and shifted,
- low statistics because of $BR_{\tau \to X}$: $o(10^3)$ vs $o(10^5)$ for $Z \to ee$.

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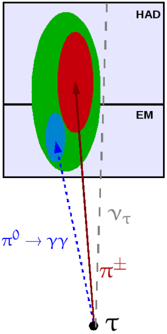
Alternative approach :



$$E^{true} = R_e E^{meas}_{\pi^0} + R_\pi E^{meas}_{\pi^\pm}$$

But :
1. calo not compensated : $R_e \neq R_\pi$
2. Can't separate the two showers

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is the **only** measured observable

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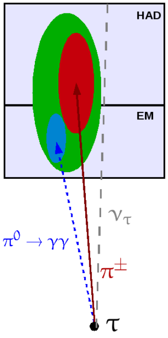

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Energy scale

- $R_e \Rightarrow Z \to ee$ calib
- $R_\pi \Rightarrow$?
- how to use R_e, R_π ?

Energy resolution

- tracker ?
- calorimeter ?
- both ?

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Absolute correction

Strategy : measure the $\pi^{\pm}$ with the tracker and π^0 with the calorimeter. To avoid double counting, the average calorimeter $\pi^{\pm}$ energy $\langle E_{cal}^{\pi^{\pm}} \rangle$ is substracted (for type 2 and 3) :

$$E_{corr} \equiv E_{trk} + E_{cal} - \underbrace{\langle R_{\pi}^{data/mc}(E_{trk}, \eta) \rangle \cdot E_{trk}}_{\langle E_{cal}^{\pi^{\pm}} \rangle}$$

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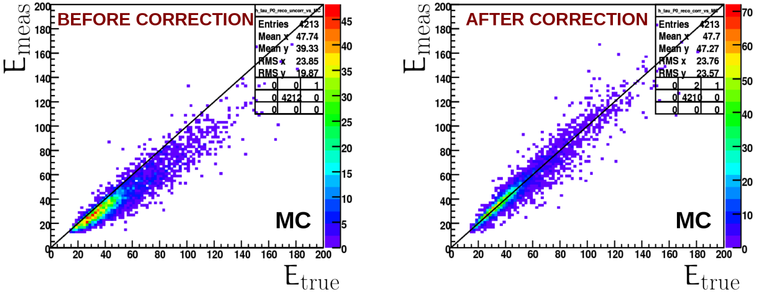
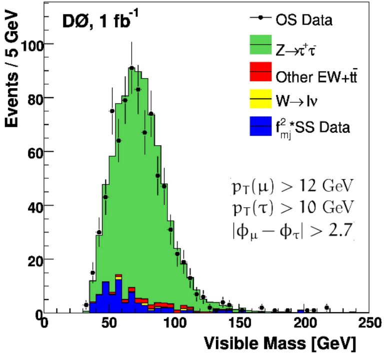
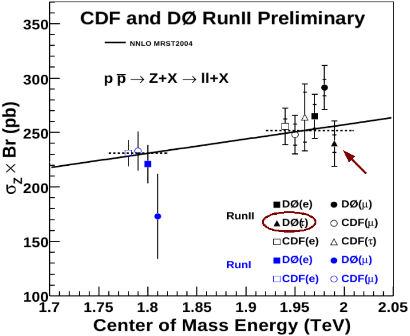


Comment : for type 1 (one track and one Cal Clu) $\Leftrightarrow$ particle flow

$\sigma(p\bar{p} \to Z \to \tau\tau)$ measurement

$\mu\tau_{had}$ final state using this energy correction method :





$$M_{vis}^2 \equiv (p^\tau + p^\mu + mET)^2$$

Phys. Lett. B 670 , 292 (2009)

Relative correction

Motivation : the *in situ* measurement of R_π **for data** in hadronic environment is difficult (requiring isolated pions). Track energy propagation can be done differently.

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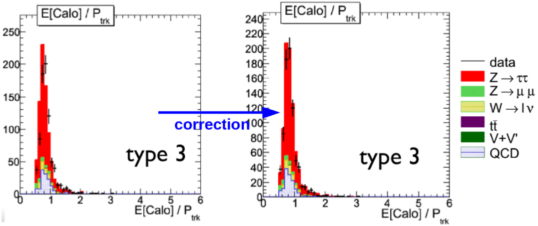
Correction method :
Use the track energy as reference to correct simulation event by event :

$$\left(\frac{E}{p}\right)_{\mathrm{MCcorr}} = \left(\frac{E}{p}\right)_{\mathrm{MC}} \times \frac{\langle E/p \rangle_{\mathrm{data}[Z\to\tau\tau]}}{\langle E/p \rangle_{\mathrm{MC}}}$$

with

- $E/p \equiv E^{\mathrm{calo}}/p^{\mathrm{trk}}$
- $\langle E/p \rangle \equiv$ average value.

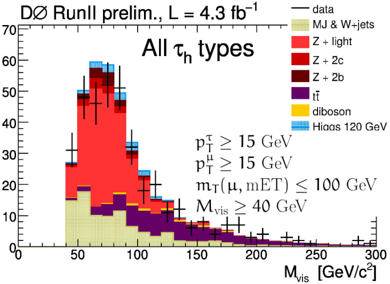


Higgs searches

Higgs searches using this energy correction method :

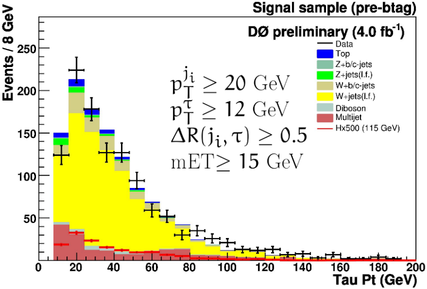
SUSY neutral Higgs ϕ

$p\bar{p} \rightarrow b\phi \rightarrow \tau\tau b$



SM Higgs

$p\bar{p} \rightarrow W(\rightarrow \tau\nu)H(\rightarrow b\bar{b})$



DØ preliminary

See next talk by Tammy on Higgs boson searches in τ final state at DØ

Conclusions and outlooks

Tau identification in hadronic environment requires sophisticated algorithms.

Promising improvements at DØ using additional τ properties and kinematic dependences.

In spite of experimental challenges, τ are well understood and allow to

- test SM consistency at high energy
- search for new phenomena
- search for the origin of electroweak symmetry breaking

next talk by Tammy

BACKUP SLIDES

Minimal Supersymmetric SM and τ's

MSSM extension :

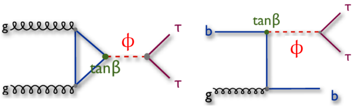
- $\tilde{q}$, $\tilde{g}$,
- weak gauginos, ...

} cascade decays can end with τ's

Higgs sector of MSSM After $SU(2)_L \times U(1)_Y$ symmetry breaking :

1. 3 neutral Higgs fields $\phi \equiv (H^0, h, A)$,
2. 2 charged Higgs fields H^+, H^-.

For the neutral Higgs search :

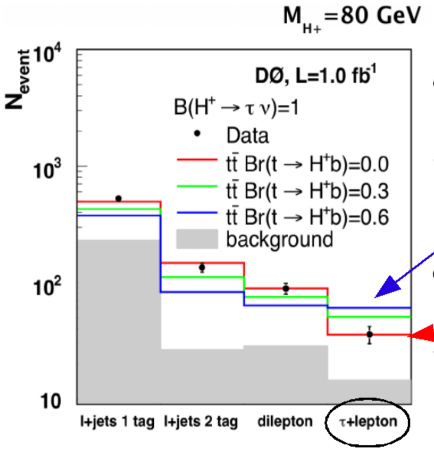


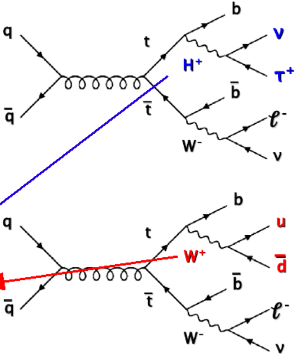
- ϕ decays in $\tau\tau$ (10%) and $b\bar{b}$ (90%)
- but $b\bar{b}$ final state : multijet bkg

Sensitive process : $p\bar{p} \to \phi \to \tau\tau$

MSSM charged Higgs

Charged higgs bosons via $t\bar{t}$ events





R_π measurement in data

Strategy : fit an improved MC in a restricted region where R_π is measured in data. Trust MC for extrapolation.