CDF τ triggers, analysis, and other developments

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CDF Collaboration

OUTLINE

- Motivation
- CDF Run II Detector/Trigger System
- τ Triggers
- τ physics analysis
- Computation of Fast Derivatives

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Motivation for τ Triggers

◊ **Standard Model:**

B physics: Υ, $(B^{\pm}, B^0, B_s)$, $(D^{\pm}, D^0, D_s)$

QCD: inclusive lepton low E_T jet, $b\bar{b}$, $c\bar{c}$

Electoweak: Drell-Yan $(\gamma, Z^0) \rightarrow \tau^+\tau^-$

Top: $t\bar{t}$ channel with $W \rightarrow \tau\nu_\tau$

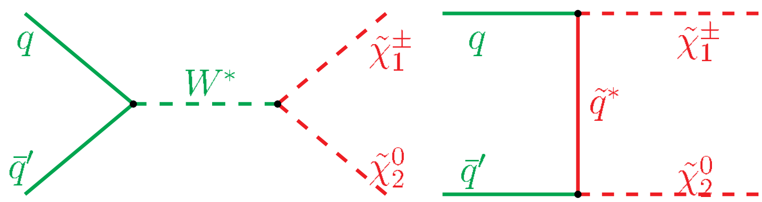
Higgs: WH^0 or ZH^0 production
with $W/Z \rightarrow \tau$ or jet, $H^0 \rightarrow b\bar{b}/\tau^+\tau^-$

◊ **Beyond the Standard Model:**

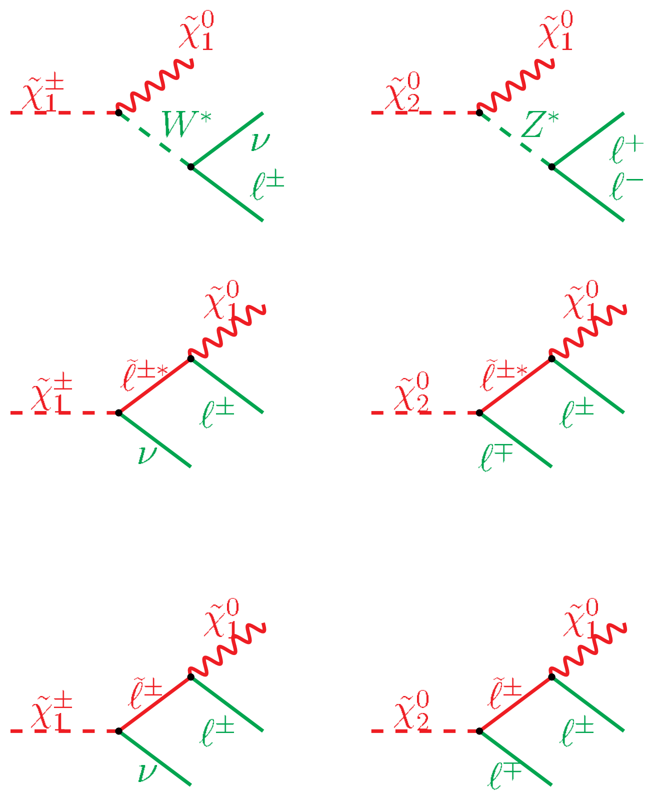
SUSY searches: $p\bar{p} \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$,

$\not{R}_p$ SUSY, MSSM Higgs, ...

Production of chargino and neutralino



Decays of chargino and neutralino

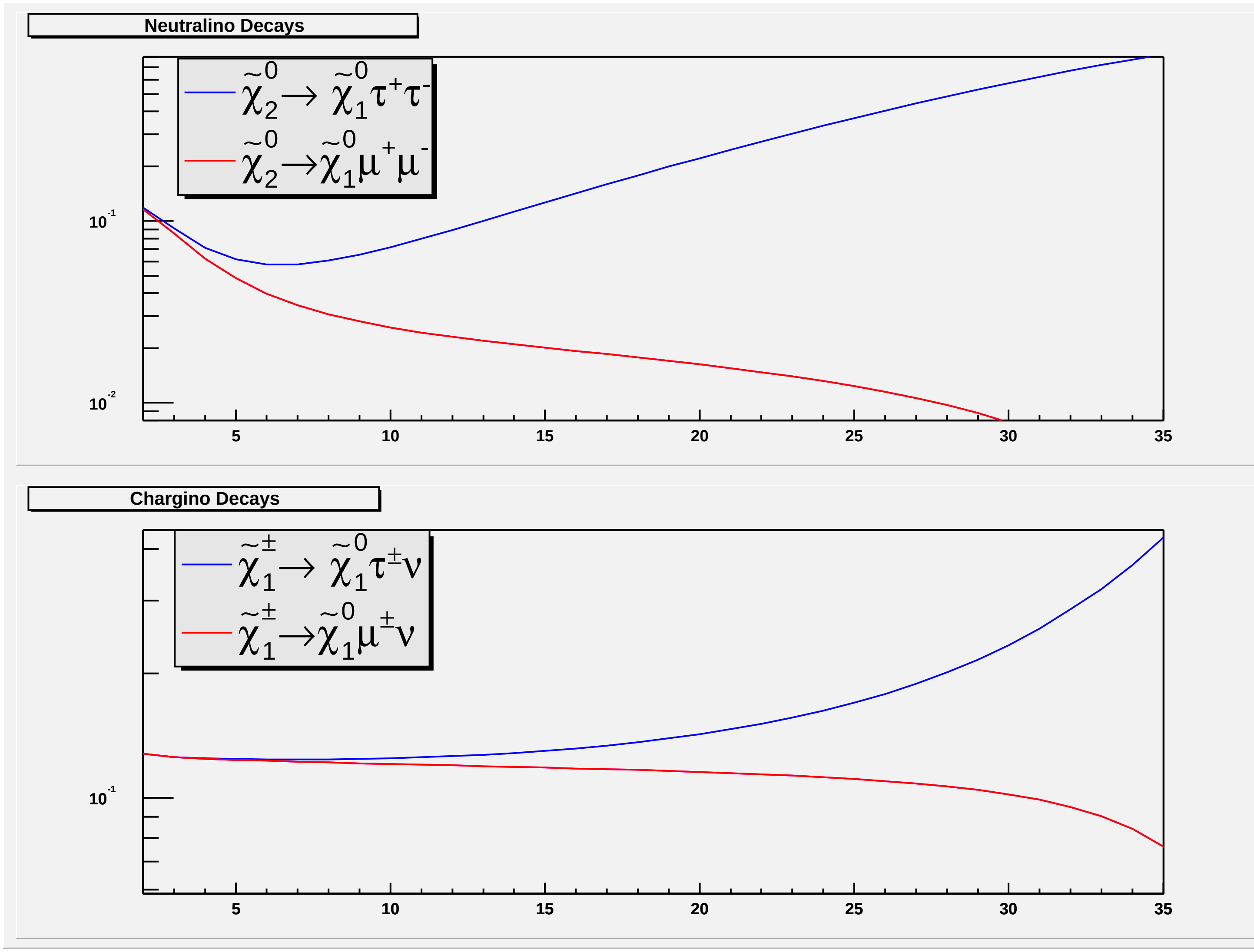


$p\bar{p} \to \tilde{\chi}_1^\pm \tilde{\chi}_2^0$ & tri-lepton decays

$\tilde{\chi}_1^\pm \to l^\pm \nu \tilde{\chi}_1^0, \quad \tilde{\chi}_2^0 \to l^+ l^- \tilde{\chi}_1^0$

Plot of Branching Ratios versus $\tan\beta$

ISAJET 7.63



$\tan\beta$

mSUGRA points: $m_0 = 150$, $m_{1/2} = 150$, $A_0 = 0$, sign$(\mu) = +1$

Wisdom from Run I

◊ **Previous searches were based on four tri-lepton channels: $eee, ee\mu, e\mu\mu$, and $\mu\mu\mu$.**

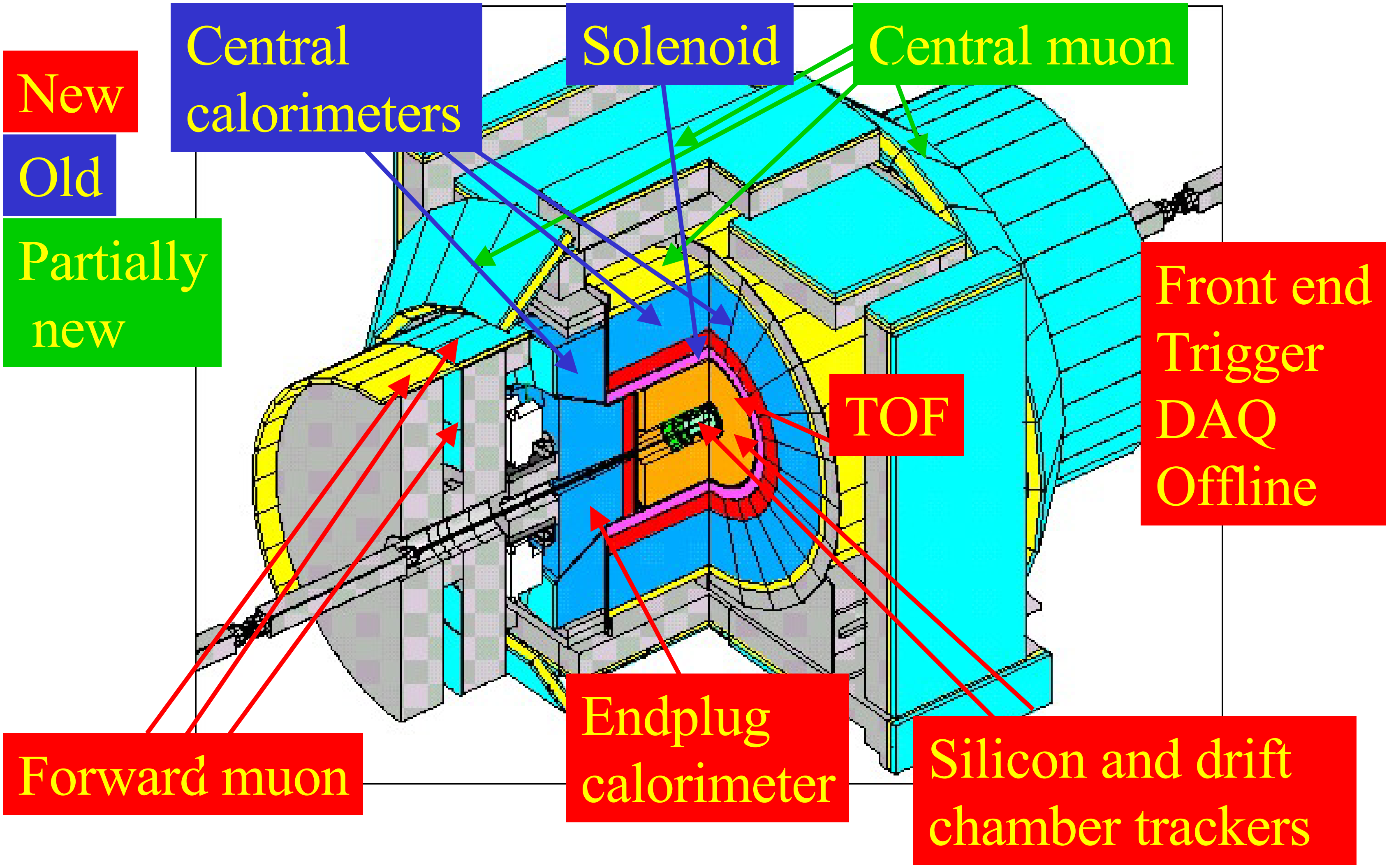
◊ **This limits the SUSY parameter space at large $\tan\beta$ where branching ratios for $\tau' s$ are dominant.**

◊ **We need triggers for leptons, including $\tau' s$, with low p_T ($\approx$ 10 GeV/c) and also another track.**

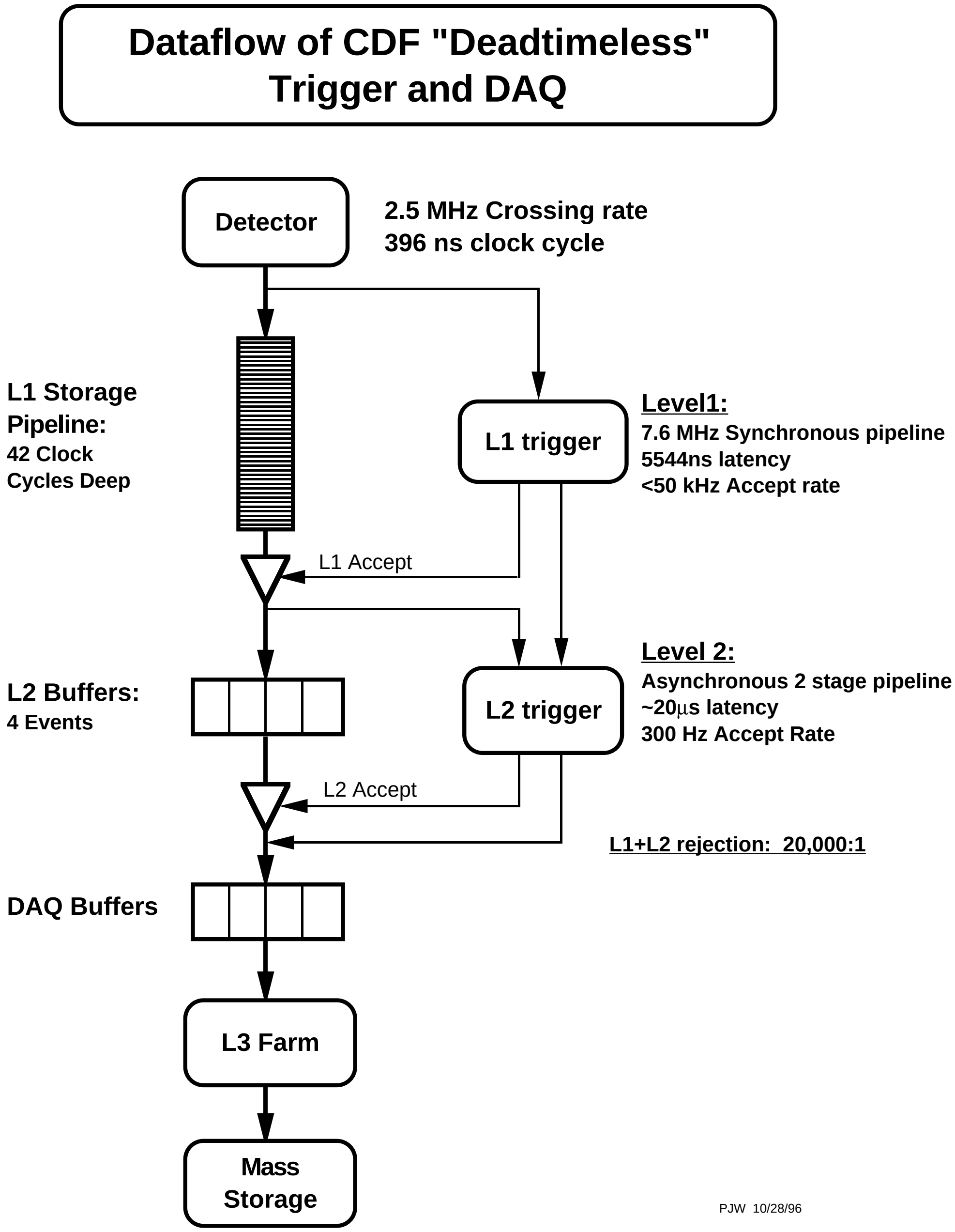
◊ **Such triggers will not only be useful for triggering on tau events, but also "pencil-like" low p_T jets (b's and c's).**

◊ **Depending on $\int \mathcal{L}\, dt$, τ's substantially extend the reach.**

The Upgraded CDF Detector



CDF Data Flow
3-Level Trigger System

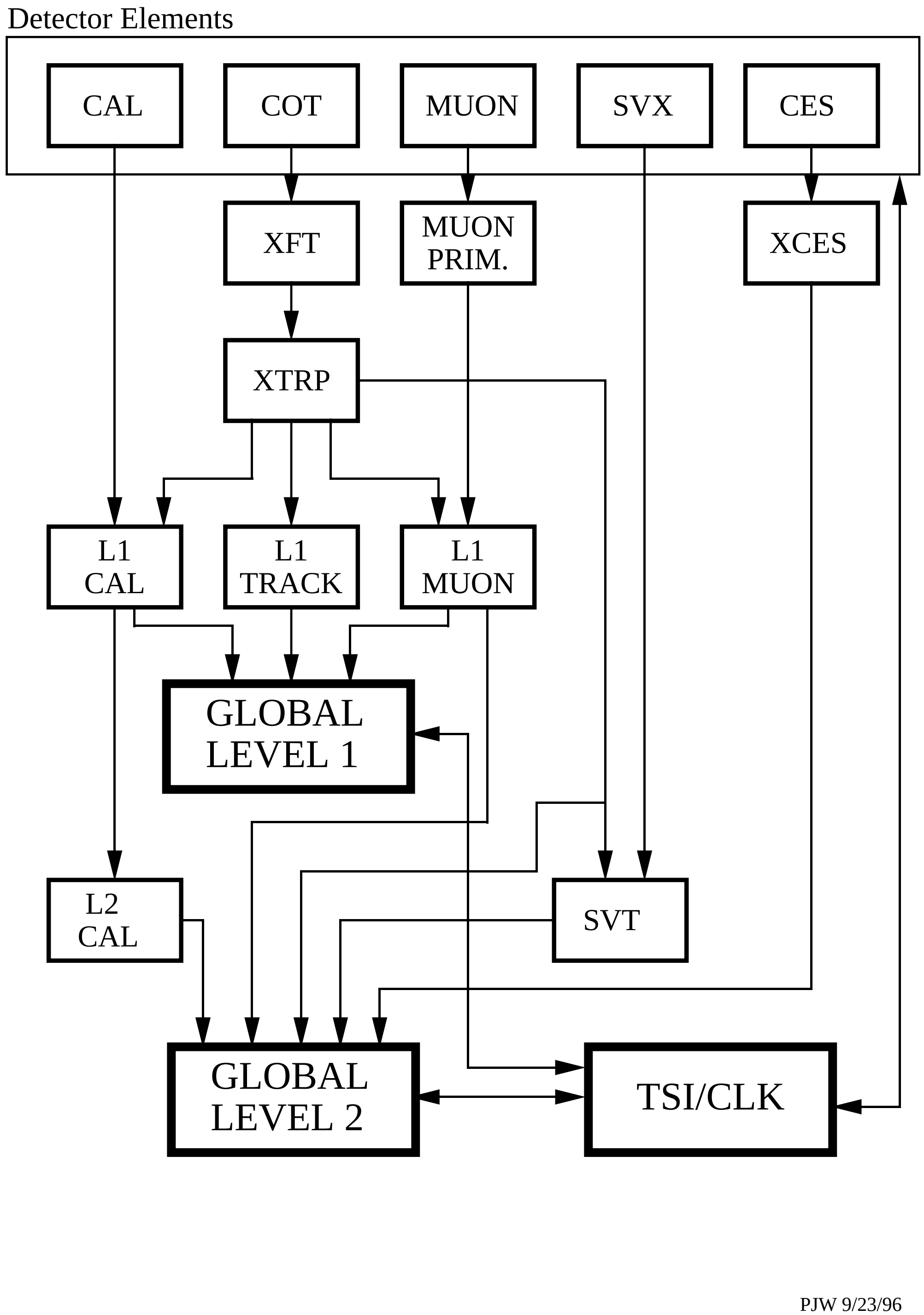


Limits: L1-40 kHz, L2-300 Hz, L3-40 Hz

L1 and L2 Custom Designed VME

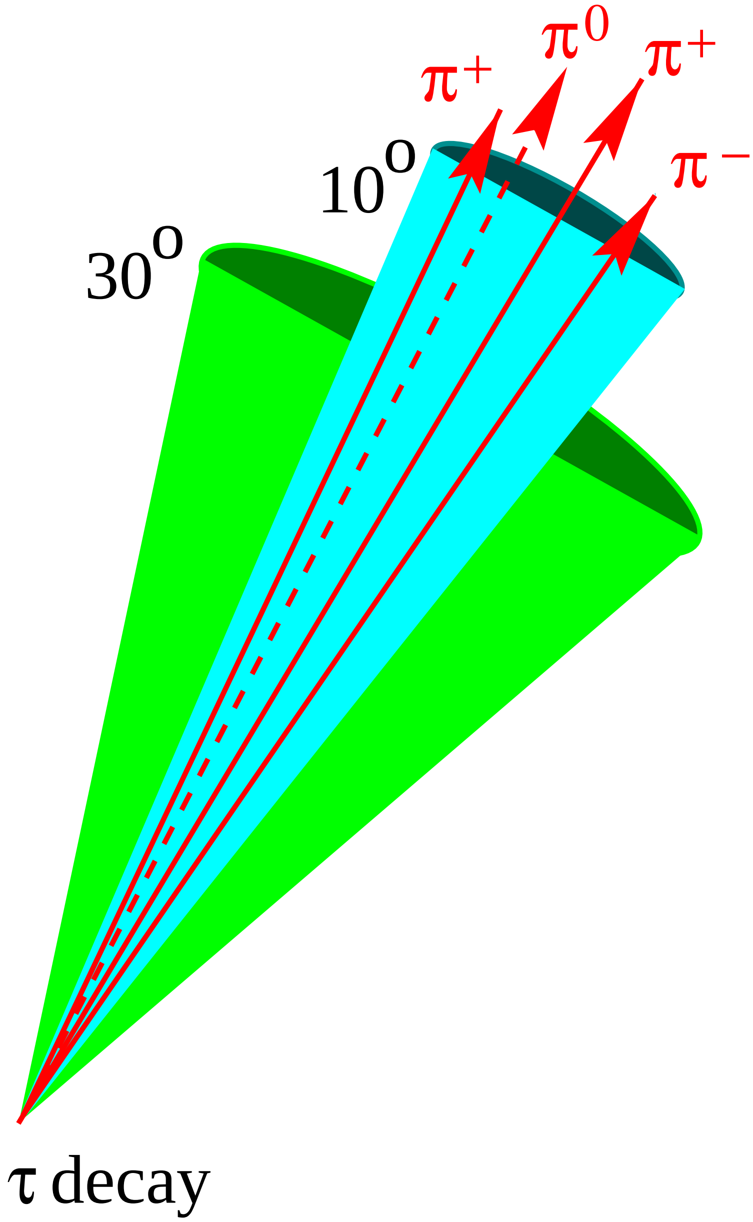
L3 Processor Farms with event reconstruction

RUN II TRIGGER SYSTEM



Tau Triggers

- ◊ **Di-Tau**
- ◊ **CMUP Muon plus track**
- ◊ **CMX Muon plus track**
- ◊ **Electron plus track**
- ◊ **Tau plus $\not{E}_T$**



Cones for τ-Trigger and Analysis

◊ Di-Tau Trigger

- **Level 1:**

  Two trigger towers

  $E_T \geq 5$ GeV

  $\Delta\eta \times \Delta\phi = 0.2 \times 0.3$

  Two tracks

  $p_T > 6$ GeV/c

  $0.52 \leq |\Delta\phi_{tracks}| \leq \pi$

- **Level 2:**

  Two jet clusters

  E_T(jet) ≥ 15 GeV, $|\eta(\text{jet})| \leq 1.1$

- **Level 3:**

  Two τ-cone objects

  $p_T \geq 6$ GeV/c, $|\eta(\tau)| \leq 1$

  $N_{track}^{10^\circ-30^\circ} = 0$

  ($p_T > 1.0$ GeV/c and $|\Delta Z_0| < 10$ cm)

  no restrictions on m_τ

◊ CMUP muon + track trigger

- **Level 1:**

  CMUP muon stub

  $p_T \geq 6$ **GeV/c (stub)**

  Associated XFT track $p_T \geq 4$ **GeV/c**

- **Level 2: Auto Accept**

- **Level 3:**

  muon matched to COT track

  $p_T(\mu) \geq 8$ **GeV/c**

  CMU $|\Delta x| < 15$ **cm**

  CMP $|\Delta x| < 20$ **cm**

  τ**-cone track requirements**

  $p_T \geq 5$ **GeV/c,** $|\eta| \leq 1.5$

  $N_{tracks}^{10^\circ - 30^\circ} = 0$

  ($p_T > 1.0$ **GeV/c and** $|\Delta Z_0| < 15$ **cm)**

  muon + τ**-cone track object**

  $|\Delta Z_0| < 15$ **cm,** $|\Delta R| > 0.175$

◊ CMX muon + track trigger

- **Level 1:**

  CMX muon stub

  $p_T > 6$ GeV/c (stub)

  Associated XFT track $p_T \geq 8$ GeV/c

- **Level 2: Auto Accept**

- **Level 3:**

  muon matched to COT track

  $|\Delta x| < 30$ cm

  $p_T > 8$ GeV/c

  τ-cone track requirements

  $p_T \geq 5$ GeV/c, $|\eta| \leq 1.5$

  $N_{track}^{10^\circ - 30^\circ} = 0$

  ($p_T > 1.0$ GeV/c and $|\Delta z| < 15$ cm)

  muon + τ-cone track object

  $|\Delta Z_0| < 15$ cm, $|\Delta R| > 0.175$

◊ Electron + track trigger

- **Level 1: EM Shower with XFT track**

  $E_T(e) > 8$ GeV, $Had/Em < 1/8$

  Associated XFT $p_T \geq 8.34$ GeV/c

- **Level 2:**

  EM Shower Cluster

  $E_T(e) > 8$ GeV, XCES > 2 GeV

  $Had/Em < 1/8$

  2nd XFT track

  $p_T > 5.18$ GeV/c

  $|\Delta\phi(e, \text{track})| > 10^\circ$

- **Level 3:**

  electron matched to EM Shower

  $|\Delta z_{\text{CES}}| < 8$ cm, $\chi^2_{\text{CES}} < 20$

  $E_T > 8$ GeV, $p_T > 8$ GeV/c

  τ-cone track requirements

  $p_T \geq 5$ GeV/c, $|\eta| \leq 1.5$

  $N^{10^\circ - 30^\circ}_{track} = 0$

  ($p_T > 1.0$ GeV/c and $|\Delta z| < 15$ cm)

  electron + τ-cone track object

  $|\Delta Z_0| < 15$ cm, $|\Delta R| > 0.175$

◊ **Tau + $\not\!\!E_T$ trigger**

- **Level 1:**

  missing E_T

  $\not\!\!E_T > 25$ **GeV**

- **Level 2: Auto Accept**

- **Level 3:**

  missing E_T

  $\not\!\!E_T > 20$ **GeV**

  τ-cone requirements

  $p_T \geq 5$ **GeV/c**, $|\eta| \leq 1.0$

  $N_{track}^{10^\circ-30^\circ} = 0$

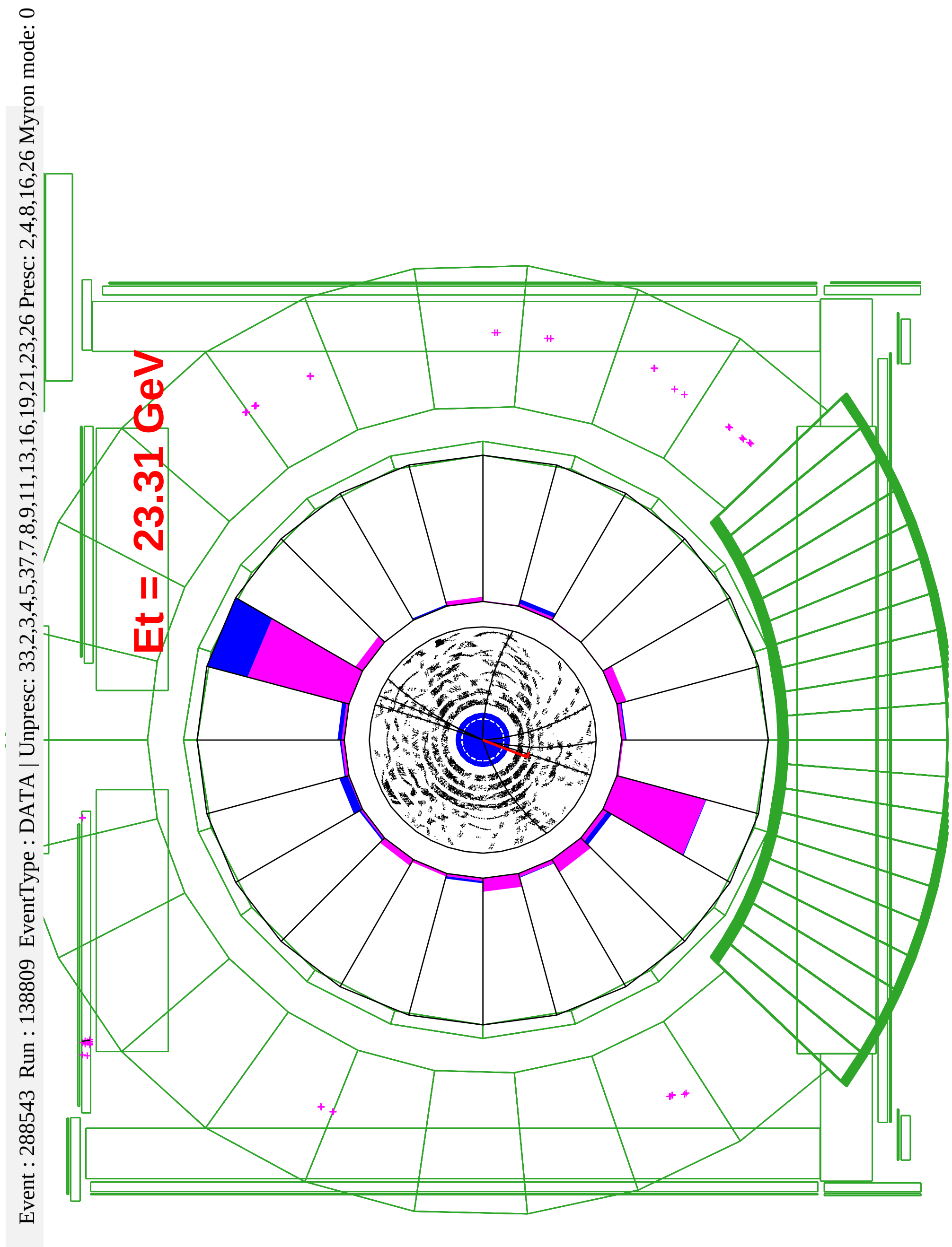
  ($p_T > 1.0$ **GeV/c and** $|\Delta z| < 10$ **cm**)

  further cuts on τ

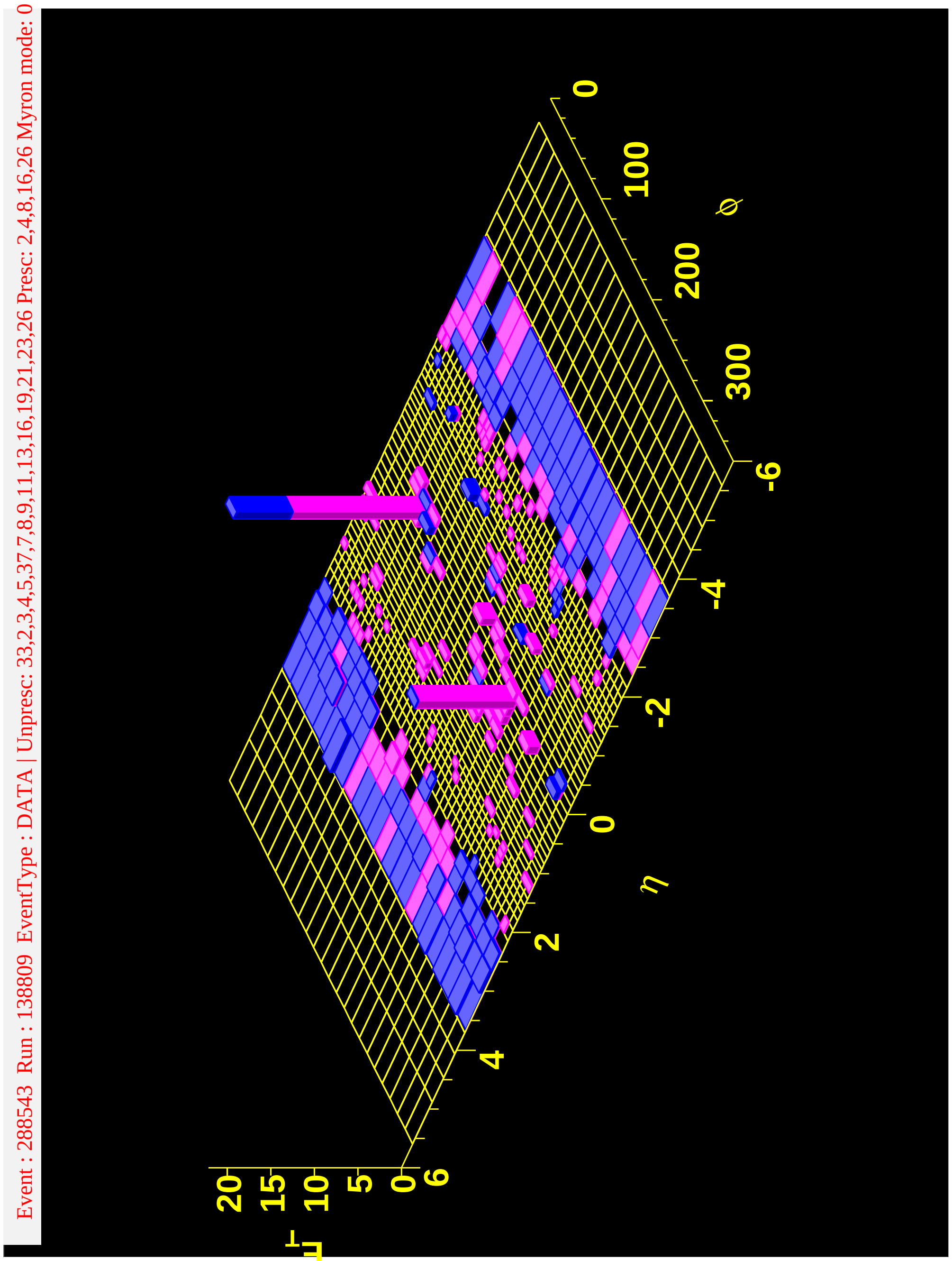
  $p_T(\tau) \geq 20$ **GeV/c**

  $m(\tau) \leq 2.0$ **GeV/c^2**

Events from Electron + Track Triggers



Events from Electron + Track Triggers



Finding Taus: $W \to \tau\nu$ first result

- "Monojet"+$\not\!\!E_T$ topology
- One central hadronic τ candidate with $E_T > 25$ GeV in $\Delta R = 0.7$ cone.

  $N_{track}^{10^\circ - 30^\circ} = 0$

  $EM/E < 1 - 0.15 * (\sum P/E)$

  calo isolation:

  $E_T(\Delta R = 0.4)/E_T(\tau) < 0.1$

  track isolation:

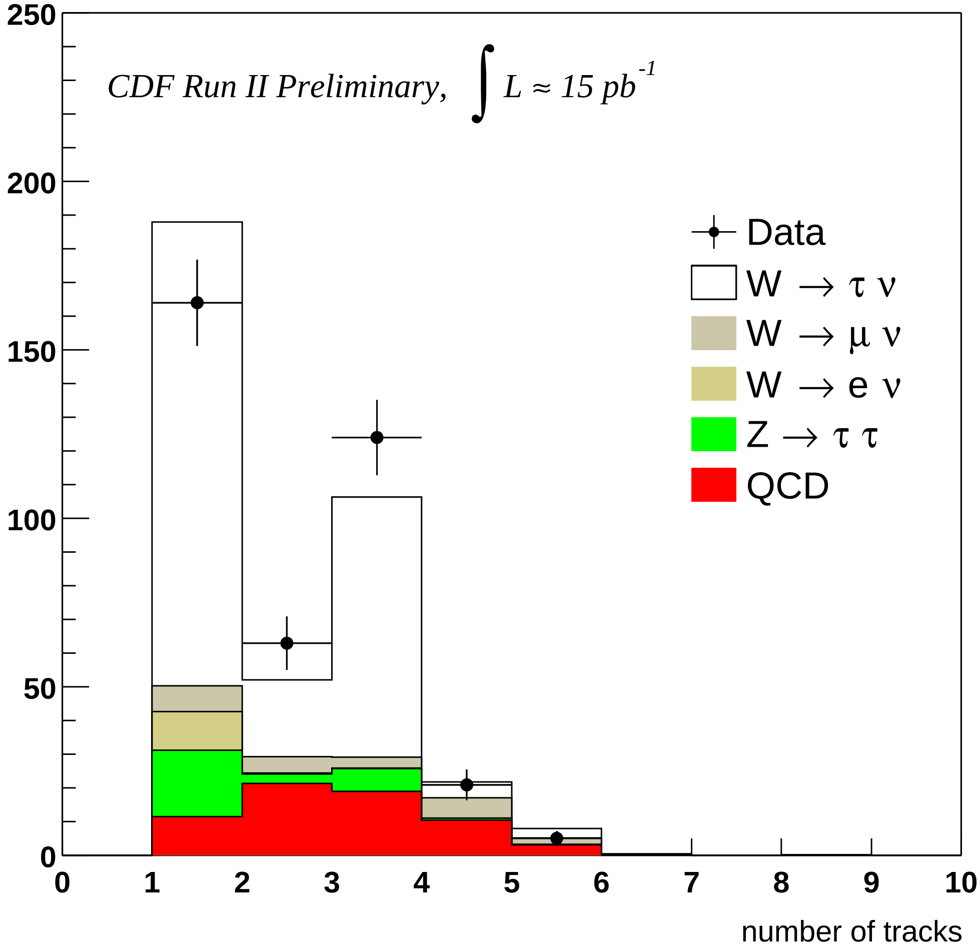
  $\sum P_T(\Delta R = 0.4)/P_T(\tau) < 0.1$

  m_τ(calo) < 5 GeV, m_τ(track) < 1.8 GeV

  fiducial cuts: CES and track vertex

- $\not\!\!E_T > 25$ GeV (calculated from τ seed)
- No other jets above $E_T = 5$ GeV
- No interacting cosmics.

W → τ ν : number of tracks, associated with the τ candidate



Fast Derivatives: Backwards Differentiation

- Function of many parameters

$$f(x_1, x_2, ..., x_n), \quad \nabla f, \quad \frac{\partial^2 f}{\partial x_i \partial x_j}$$

- Technique Common in Computer Science
  Automatic Differentiation Conferences
  Special Case: Backpropagation in ANN
  Should be more widely known

- Many areas of application
  Gradient Descent, Hessian calculation,
  Kalman Filter:
   linearization & covariance
  multivariate χ^2 minimization,
  alignment, tracking, ANN,...

- Description of General Algorithm

Consider Ordered List of Computations

$$\begin{aligned} h_1 &= f_1(\Omega_1) \\ h_2 &= f_2(\Omega_2) \\ h_3 &= f_3(\Omega_2) \\ &\vdots \\ h_r &= f_r(\Omega_r) \end{aligned}$$

where $\Omega_k \subseteq \vec{x} \cup \{h_i : i < k\}$ and $\vec{x}$ is a set of n parameters. For simplicity assign $h_1 = x_1, h_2 = x_2, ..., h_n = x_n$, so we may assume $\Omega_k \subseteq \{h_i : i < k\}$.

Important to remember that h_r represents our computation of $f(x_1, x_2, ..., x_n)$.

Forward Differentiation (chain-rule) beginning with the first line and proceeding forward, starting with i=1,

$$\frac{\partial h_i}{\partial x_j} = \sum_{k=1}^{i-1} \frac{\partial f_i}{\partial h_k} \frac{\partial h_k}{\partial x_j}$$

and continuing until i=r. Computation of ∇f takes one-pass through entire list for each parameter x_j. SLOW

Object is to compute ∇f quickly

Rules for Backward Differentiation: ∇f

Let $\vec{F}$ be an array of length r. Start at the Bottom of the List of Computations and work backward towards the beginning of the list.

- **Initialize: $F_i = 0$, for $i < r$, $F_r = 1$**
- **$F_i \rightarrow F_i + F_k[\partial f_k / \partial h_i]$, for all i where $h_i \in \Omega_k$, $k = r, r-1, ..., n+1$**
- **∇f: $\partial h_r / \partial x_i = F_i$, $i = 1, 2, ..., n$**
- **and, in general, $\partial h_r / \partial h_i = F_i$, $i = 1, 2, ..., r$**
- **∇f computed in one backwards pass!**

Must be able to determine i and k going backward and compute $\partial f_k / \partial h_i$ dynamically from $h_1, h_2, ..., h_r$.

Second Derivatives: $\partial^2 f/\partial x_v \partial x_i$

Apply backward differentiation twice.

Let $\vec{F}$ be provided from before and let $\vec{S}$ and $\vec{Q}$ be arrays of length r.

1a: $Q_v = 1, Q_i = 0$ for $i \neq v$ and
$v \in \{1, 2, ..., n\}$

1b: $S_j = 0 \, \forall \, j$

2a: $Q_k \rightarrow Q_k + Q_i[\partial f_k/\partial h_i], \forall h_i \in \Omega_k$

2b: $S_j \rightarrow S_j + F_k Q_i[\partial^2 f_k/\partial h_i \partial h_j], \ (h_i, h_j) \in \Omega_k$

$k = n+1, n+2, ..., r$

3: $S_i \rightarrow S_i + S_k[\partial f_k/\partial h_i], \ \forall h_i \in \Omega_k$

$k = r, r-1, ..., n+1$

4: Then $\partial^2 f/\partial x_v \partial x_i = S_i, \ i = 1, 2, ..., n$

$\vec{Q}$ calculated by forward differentiation.
Step-3$\rightarrow$ first derivative calculation.
One row of $\partial^2 f/\partial x_v \partial x_i$ for each v.
$n \times n$ Hessian computed with n passes.

Some uses for Backwards Differentiation

- **Multivariate χ^2 minimization**
  - **Newton-Raphson technique**
    - **Alignment problems**
    - **Finite Element Analysis**
    - **Maximum Likelihood**
- **Kalman Filter**
  - **Linearization of input functions**
  - **Estimating covariances**
- **ANN**
  - **Backpropagation of weights and thresholds**

Conclusions

◊ **Tau Physics is very important in Run II.**

- **SUSY searches at large** $\tan\beta$
  $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$**, MSSM Higgs,...**
- **Precision Electroweak,** $t\bar{t}$**, Higgs**

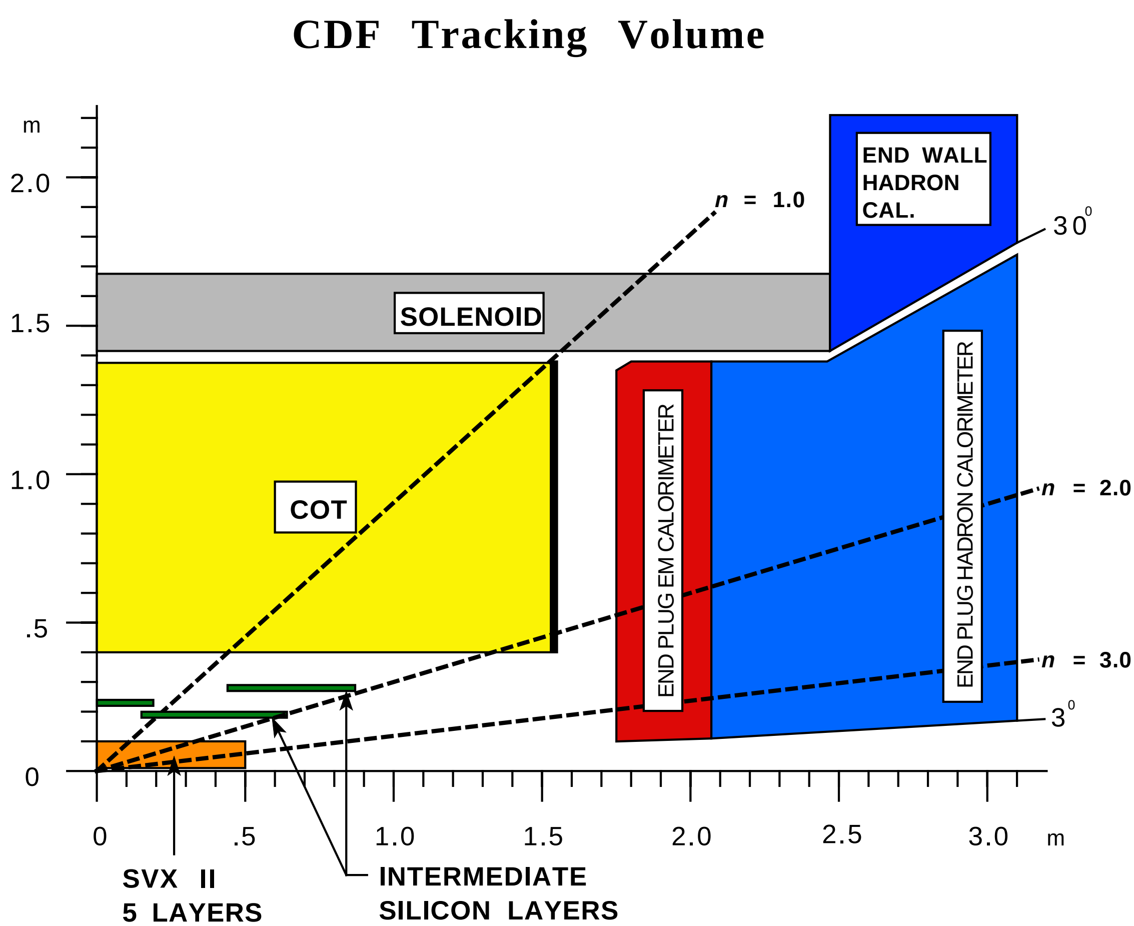
◊ **Tau Triggers installed and being commissioned at CDF.**

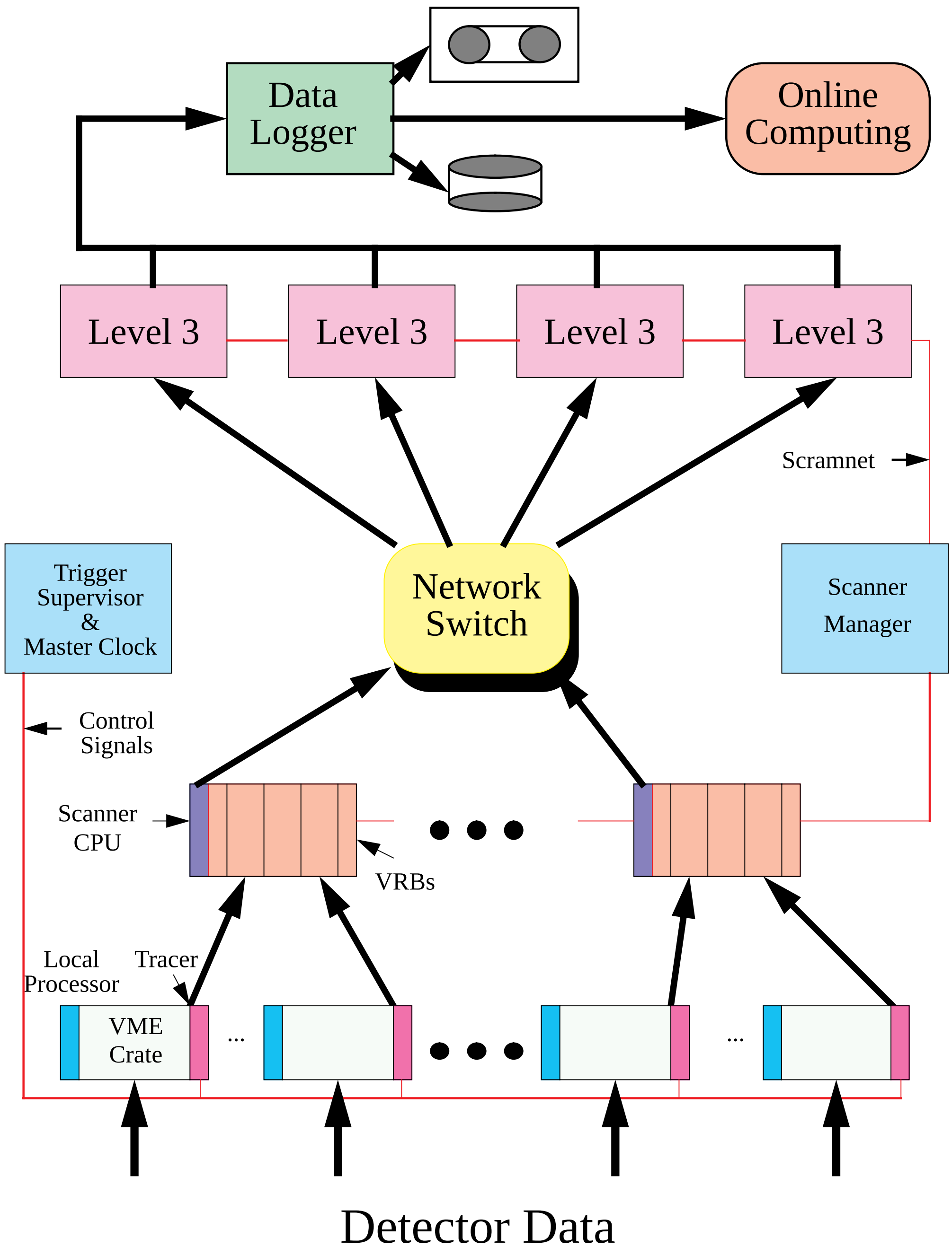
- **Data is already coming in**
- **First results** $W \to \tau\nu_\tau$
- **Ready for Winter Conferences**

◊ **Looking Forward to** $\mathcal{L} = 2\ \mathrm{fb}^{-1}$ **in Run IIa and for more data in Run IIb.**

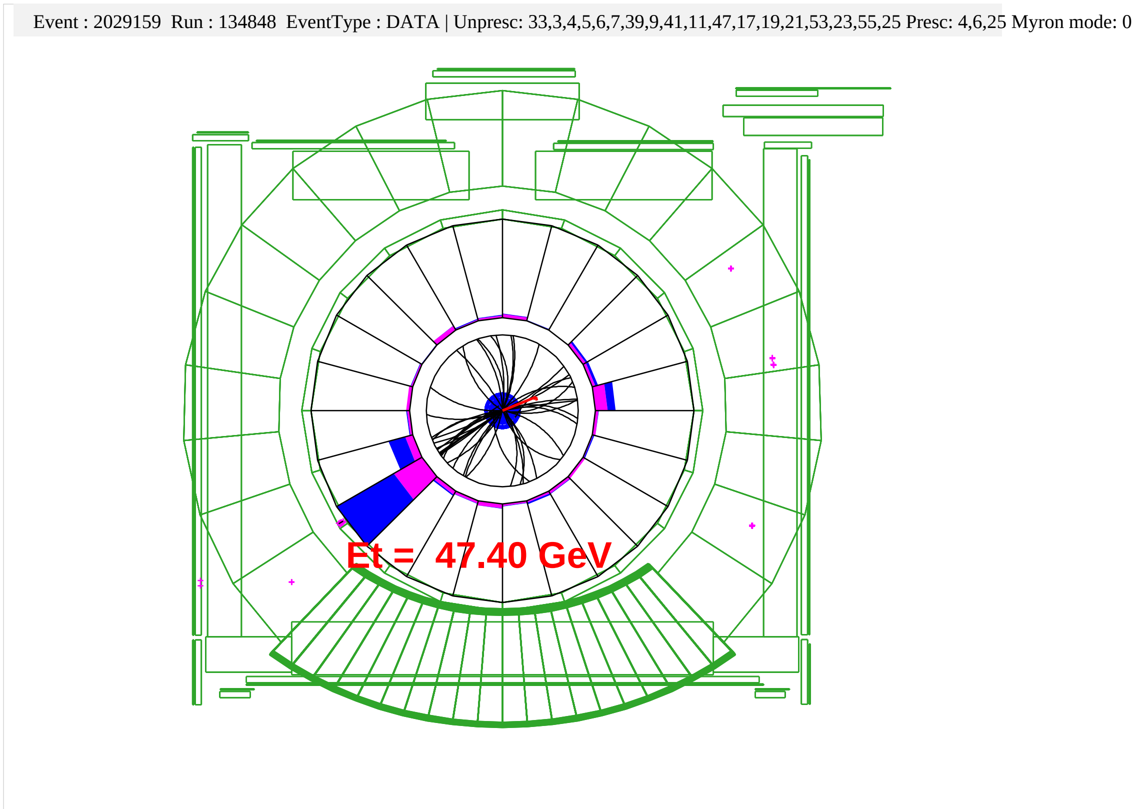
◊ **Backwards differentiation provides a useful means for optimizing programs.**

The CDF Run II Upgrage Detector




Data
Logger
Online
Computing
Level 3
Level 3
Level 3
Level 3
Scramnet
Trigger
Supervisor
&
Master Clock
Network
Switch
Scanner
Manager
Control
Signals
Scanner
CPU
VRBs
Local
Processor
Tracer
VME
Crate
Detector Data

Events from Tau + $\not\!\!E_T$ Triggers



Events from Tau + $\not\!\!E_T$ Triggers