Report from the LPC JetMET group

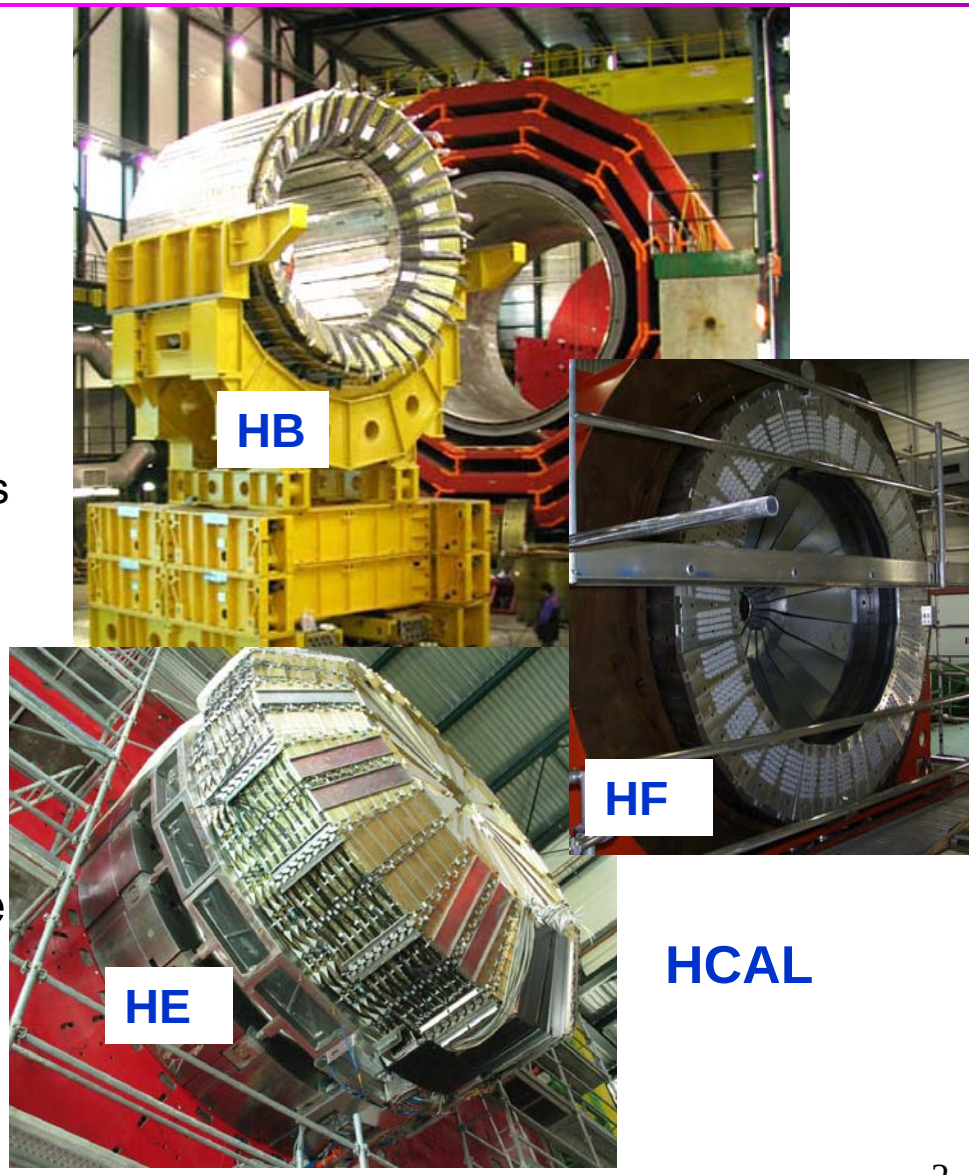
Robert Harris
Fermilab

Marek Zieliński
Rochester

Advisory Council Review of LPC
22 October 2004

Outline

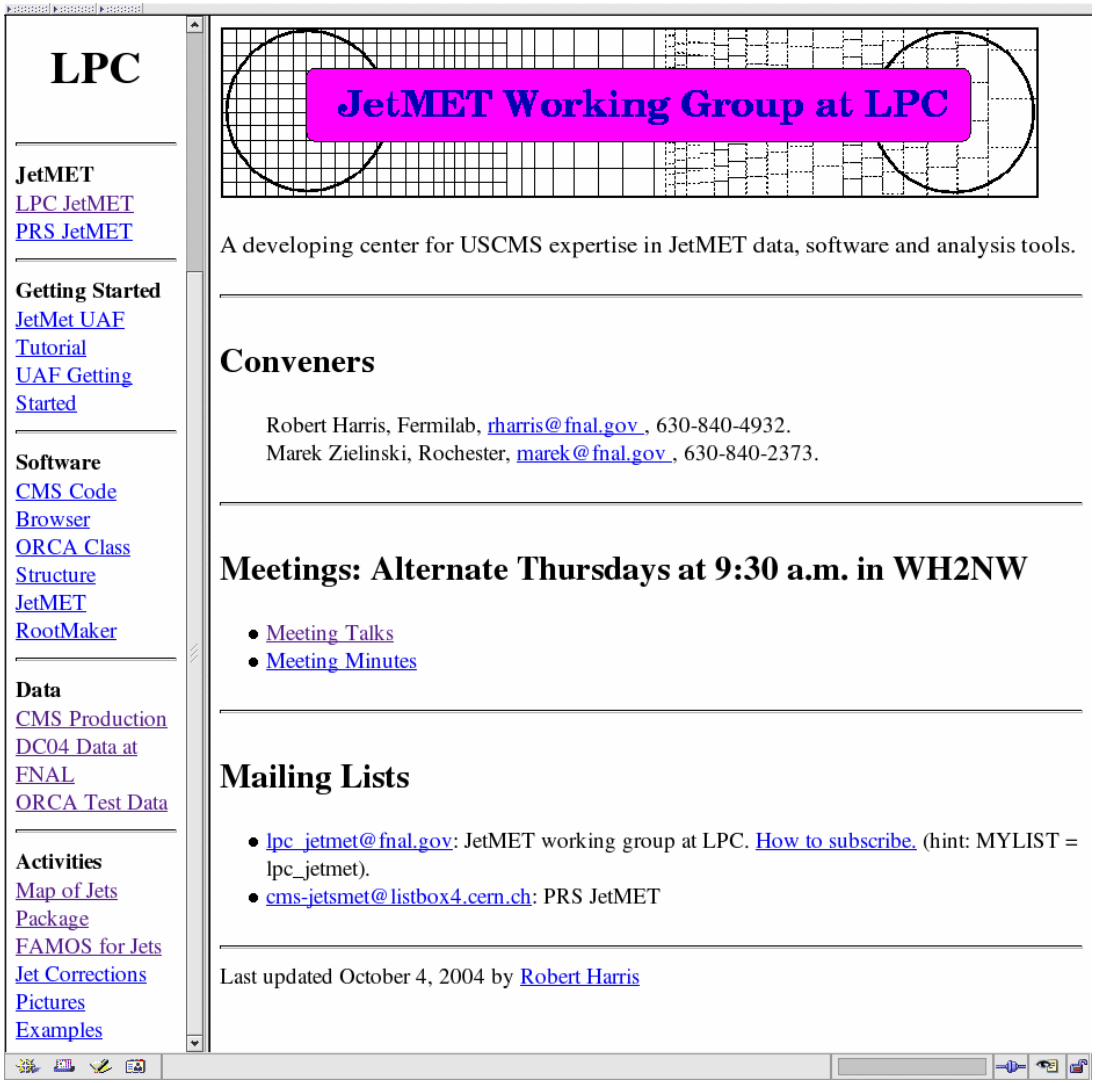
- The LPC JetMET group
  - Members
  - Relation to CMS
  - Ongoing efforts
- Calorimeter Issues
  - Detector aspects
  - Geometry: $\eta-\phi$ map of calorimeter towers
  - Lego display
- Jet studies:
  - Jet algorithms and software
  - Analyses: response and corrections
  - Simulation: OSCAR and FAMOS
- MET studies: resolution, significance
- Plans for Physics TDR, future work
- Conclusions and Outlook



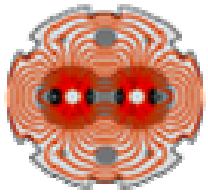
HCAL

LPC JetMET Information

- Web page
  - http://www.uscms.org/scpages/general/users/lpc_jetmet/lpc_jm.html
  - Current information on data, software and getting started in JetMET
- Conveners
  - Robert Harris (CMS & CDF) rharris@fnal.gov
  - Marek Zieliński (CMS & DØ) marek@fnal.gov
- Mailing List
  - lpc_jetmet@fnal.gov
- Meetings
  - Bi-weekly
  - Agenda available from http://agenda.cern.ch

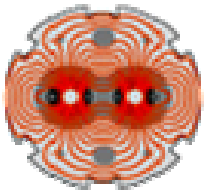


LPC JetMET Members



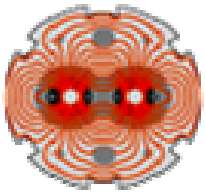
- Heads
  - Rob Harris (FNAL) and Marek Zieliński (Rochester)
- At FNAL
  - Daniel Elvira (FNAL), Marc Paterno (FNAL)
  - Shuichi Kunori (MD), Jordan Damgov (FNAL), Taylan Yetkin (FNAL), Kenan Sogut (FNAL), Selda Essen (FNAL), Stefan Piperov (FNAL)
- Away
  - Salavat Abdullin (FNAL), Lalith Perera (Rutgers), *Maria Spiropulu (CERN)*
- Joining
  - Alexi Mestvirshvili (Iowa), Dan Karmgard (Notre Dame), Taka Yasuda (FNAL), Nobu Oshima (FNAL), Weimin Wu (FNAL)

Relation to Broader CMS



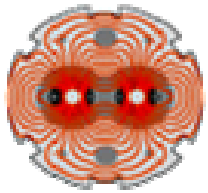
- Working with the PRS JetMET group
  - Our work on jet studies began within PRS JetMET
  - Contributing to PRS meetings
  - Frequent communications on current issues, coordination
  - Chris Tully has attended our meetings, provides guidance
- Collaborating with Fermilab HCAL group
  - Participating in mutual meetings
  - HCAL people becoming active in LPC JetMET
  - Opportunity for a leading calorimetry-based software effort at Fermilab, complementing the well-established hardware role
- Interacting with other LPC groups

Ongoing LPC JetMET Efforts



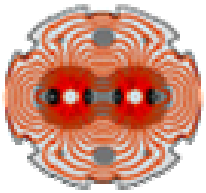
- Learning about detectors, JetMET & calorimeter software
- Jet studies
  - Jet energy response and corrections as a function of P_T and η
- MET studies:
  - Resolutions and significance
- Simulation
  - Compare response to jets and pions in FAMOS and OSCAR
  - Test/tune FAMOS simulation to make sure it is adequate for jet use
    - In coordination with the LPC and CMS Simulation groups
- Aiming for a growing role in support and development of jet and missing-E_T software

Ongoing Efforts II - HCAL/Test Beam



- TB2002-TB2004 analysis -- data taking finished this Monday
  - Extraction of key parameters for detector simulation and event reconstruction
    - Pulse shape, pulse timing, electronics noise, ADC-to-GeV, etc.
  - Checking detector effects
    - Gaps, uniformity, abnormally large signal, etc.
  - Development of algorithms for calibration, monitoring and data validation
  - Test of GEANT4 physics
    - e/π, resolution, longitudinal & transverse shower profiles
    - 3--300 GeV beams, with particle-ID (p, K, π, e) below 9 GeV
- Physics benchmark studies starting – Goals:
  - Identify issues in reconstruction and triggering, develop/improve algorithms
  - Provide experience of physics analysis to young members
- Software development and maintenance
  - JetMET RootMaker (J. Damgov)
  - HF Shower library (T. Yetkin)
  - HCAL database

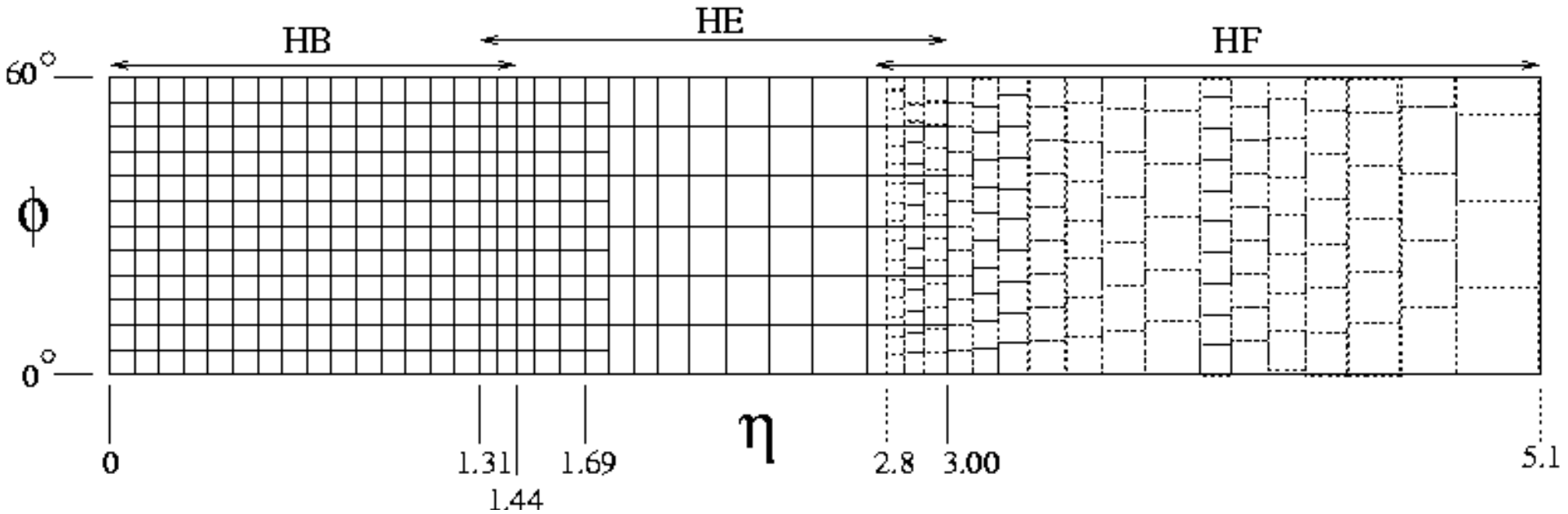
Aspects of CMS Calorimetry



- Learning calorimetry issues that impact JetMET:
  - Several detectors contribute:
    ECAL, HB (Barrel), HO (Outer), HE (Endcap), HF (Forward)
    - → Complexity of geometry: overlaps, gaps, transition regions
  - Different detection technologies in use:
    - → $PbWO_4$ crystals (ECAL), scintillator (HB, HO, HE), quartz fibers (HF)
  - Essential feature: Non-compensation
    - → e/h ~1.6 ECAL, ~1.4 HCAL
    - → Non-linear response vs. energy
  - Significant tracker material before the calorimeters (0.2--0.4 λ_0)
  - Significant noise levels (hundreds of MeV/channel)
  - Inside high magnetic field (affects signals, sweeps low P_T particles…)
  - Event pileup (~3 events/crossing even for low luminosity)
- Challenge for algorithms to maximize performance

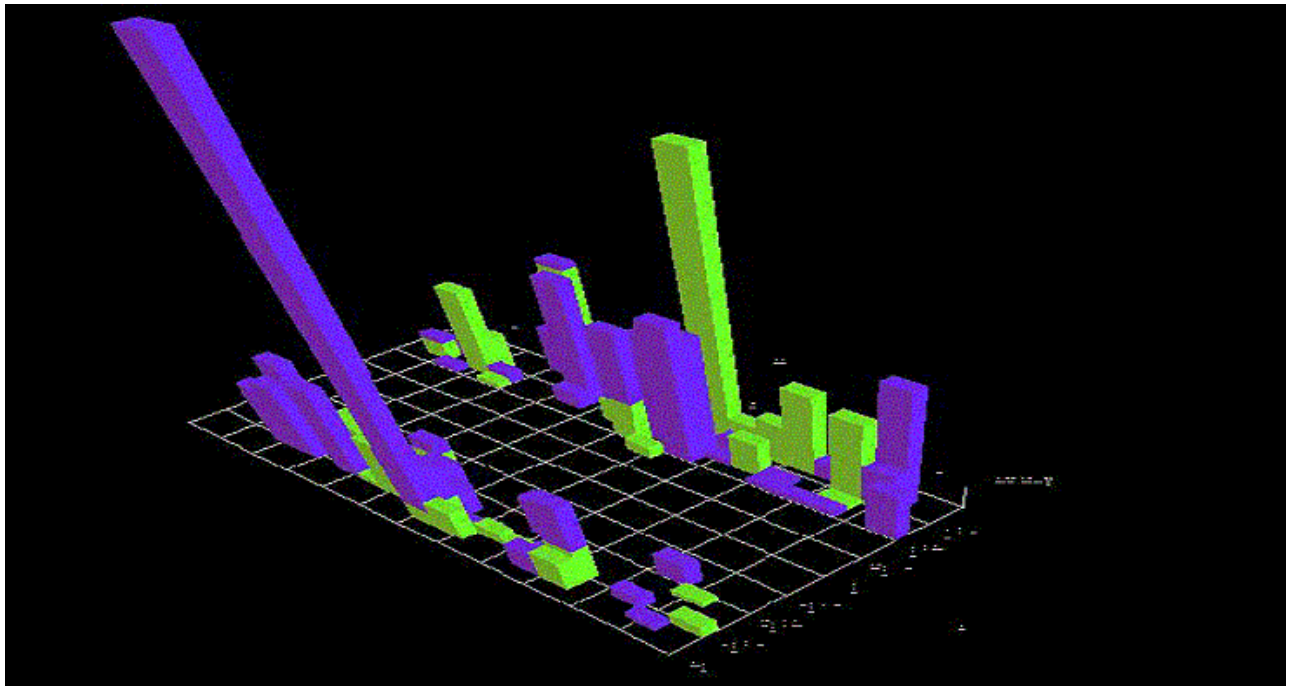
Calorimeter: Geometry

- Understanding of geometry crucial for code development and interpretation of simulations
- η-ϕ map of HCAL towers
  - ➔ Constructed a map from information in HCAL TDR, updates ongoing
  - ➔ Verification of geometry in software vs. actual construction
    - → Connection to HCAL experts is an invaluable resource

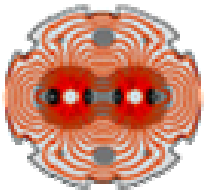


Calorimeter: a Lego-plot Display

- Communicating with IGUANA experts at CERN
  - The functionality of the lego display was requested by the LPC JetMET
    - We are involved in testing and provide feedback to developers
  - Initial “toy” version displayed simulation hits only in the Barrel (below)
  - A display of EcalPlusHcalTowers for all regions is being developed

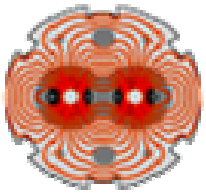


CMS Jet Algorithms



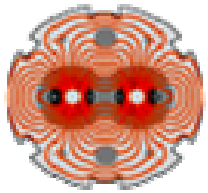
- CMS jet algorithms can cluster any 4-vectors: partons, particles, towers etc.
  - Cone algorithms (with different cone sizes and recombination schemes)
    - SimpleConeAlgorithm
      - Throws a cone around a seed direction (i.e. max P_T object)
    - IterativeConeAlgorithm
      - Iterates cone direction until stable
    - MidPointConeAlgorithm – CMS version: no splitting/merging (same as above)
      - Uses midpoints between found jets as additional seeds
    - MidPointConeAlgorithm – Tevatron RunII version, with splitting/merging
  - KT algorithms: iterative clustering based on relative P_T between objects
    - KtJetAlgorithm
      - Iterates until all objects have been included in jets (inclusive mode)
    - KtJetAlgorithmDcut
      - Uses the stopping size-parameter D_{cut}
    - KtJetAlgorithmNjet
      - Forces the final state to decompose into N jets
- A more comprehensive “vertical slice” of the jet reconstruction code, from calorimeter towers to jet information in root trees, is included in the backups

Examples: Building and Running



- We have provided basic examples of user code and scripts to help new contributors get started
  - Tool to test/debug jet reconstruction by printing out jet η and ϕ
  - Code to create a simple root tree with selected jet variables
  - Examples include:
    - Scripts to compile and link the programs on CMS UAF
    - Generic script to run the programs on CMS UAF
    - Script that runs the jobs on a specific DC04 dataset (QCD)
    - Typical output logfiles
    - A small output root-tree
- The web page points to additional resources, full-blown JetMET tutorials, UAF information, software tools and Monte Carlo data

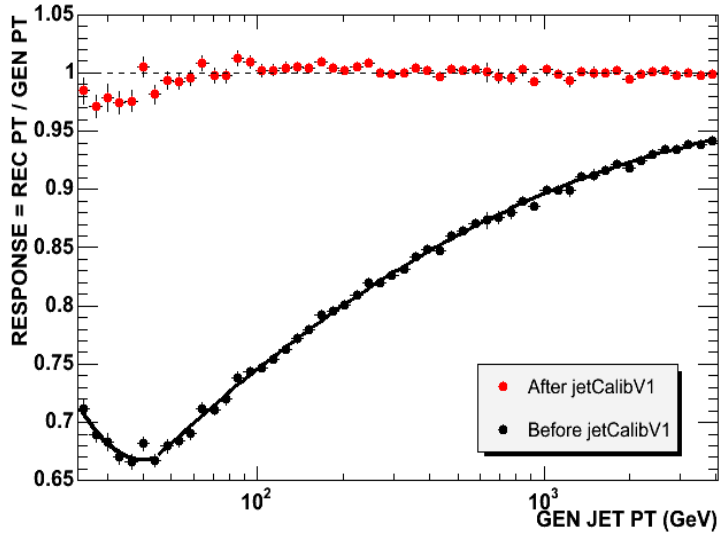
Studies of Jet Response and Corrections

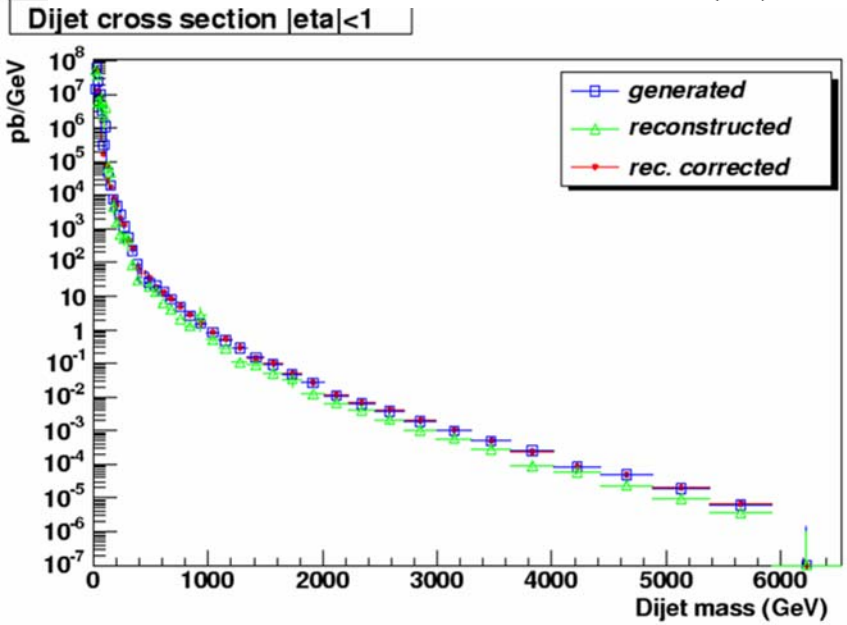


- Work has been requested by PRS JetMET group
  - Correction software completed and available to CMS in ORCA
- The issue: P_T of reconstructed jet is not same as of the particles in the jet
  - Calorimeter has non-linear response to charged pions and jets vs. P_T
  - Calorimeter has significant response variations vs. η
- The goal: provide software to correct the reconstructed jet P_T back to the particles in the jet
  - Current study is based on the knowledge of "Monte Carlo truth"
  - Need to develop data-based methods for jet calibration (e.g. using response to tracks and P_T-balancing in dijet, γ-jet and Z-jet systems)
- We determined, as a function of jet P_T and η:
  - Response = Reconstructed Jet P_T / Generated Jet P_T
  - Correction = 1 / Response

Jet Corrections and Closure Tests

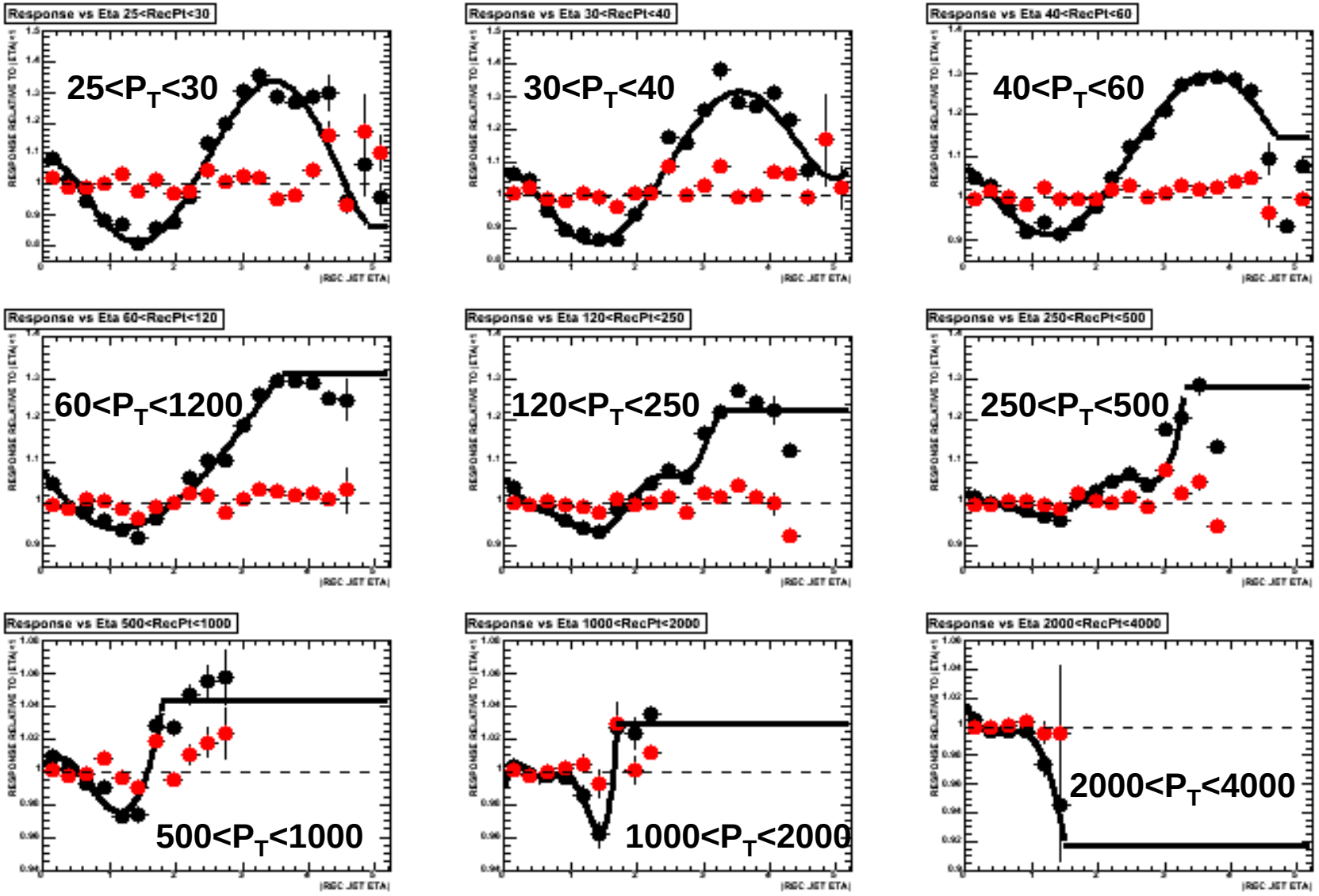
- Response study used QCD dijet samples, P_T^{Gen} = 15 -- 4000 GeV
- The measured average response was parameterized vs. jet P_T and η
  - For Iterative Cone, R = 0.5, tower E > 0.5 GeV, lum = 2 x 10^{33} $cm^{-2}s^{-1}$
- After corrections:
  - Recover particle-jet P_T (before pileup)
  - Response functions become flat
- Verification:
  - Closure tests good to a few %
  - Corrections work OK for the reconstructed dijet mass spectrum





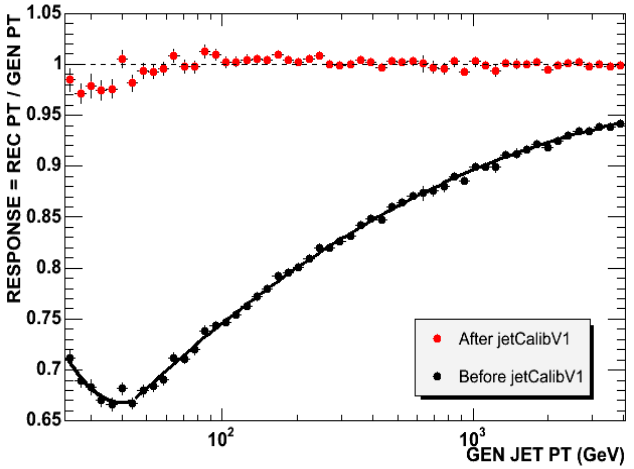
Jet Response vs. η (Relative to |η| < 1)

- Before Corrections
- After Corrections

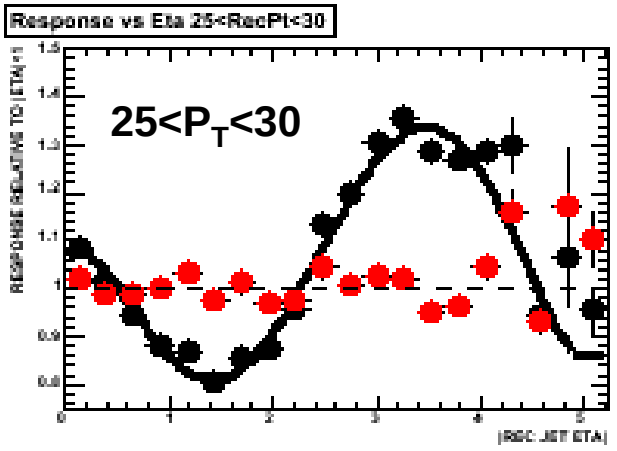


Discussion of Jet Response vs. P_T & η

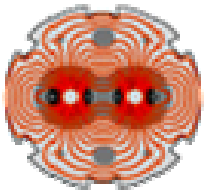
- Jet response vs. P_T:
  - Rises with increasing P_T for $P_T > 40$ GeV
    - As expected from non-linearty of calorimeters
  - Rises with decreasing P_T for $P_T < 40$ GeV
    - Interpreted as a result of contributions from noise and of tails in the resolution



- Jet response vs. η:
  - In Barrel: decreases with increasing η
    - Noise contribution to jet energies is ~several GeV and its influence on P_T diminishes with increasing η
  - In Endcap: increases with increasing η
    - Due to improved linearity for higher E, and to soft particles spiraling into the Endcap
  - In Forward: higher than in Barrel or Endcap
    - May be partially due to HF calibration in MC

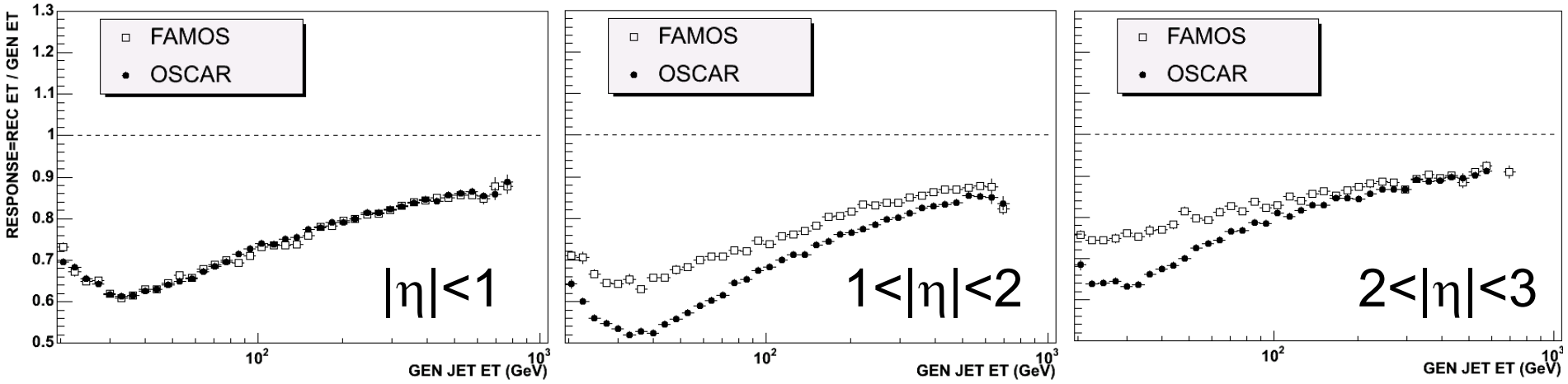


Studies for FAMOS



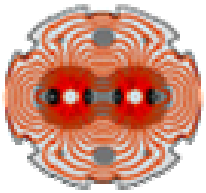
- PRS JetMET requested involvement of the LPC JetMET group
- CMS needs a reasonably accurate and fast simulation for jets
  - FAMOS is three orders of magnitude faster than OSCAR at high P_T
- We investigated the current status of FAMOS for jets
  - First step – done
    - Compare FAMOS and OSCAR for jet response and resolution
    - Compare the basic parameters in FAMOS to those for testbeam
  - Next steps:
    - Tune FAMOS parameters to OSCAR
    - Port CMSJET/GFLASH implementation of fast showering
    - Deadline for tuning of HCAL in FAMOS is Dec. 2004 for Physics TDR

Mean Jet Response vs. P_T and η



- FAMOS / OSCAR response comparisons:
  - Good agreement for $|\eta| < 1$
  - FAMOS response is higher than OSCAR for $|\eta| > 1$, needs tuning
- Distributions of response are in reasonable agreement (see backups)

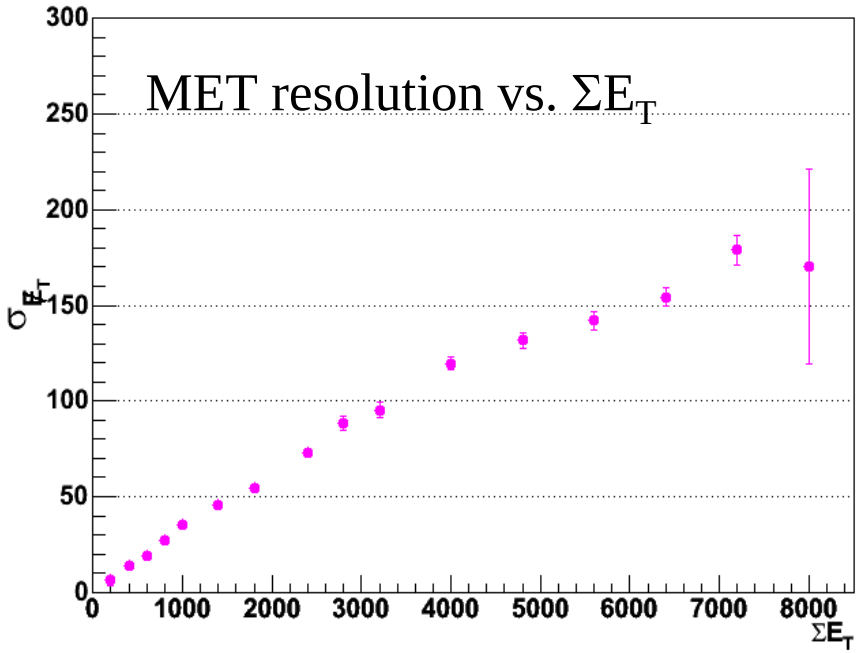
MET Reconstruction

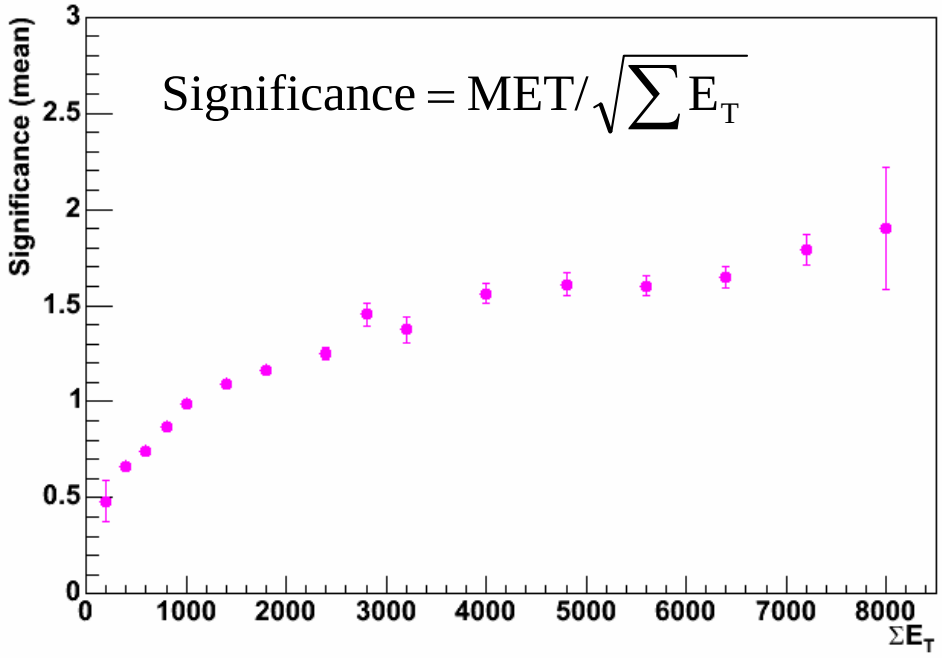


- Several levels of MET reconstruction
  - From calorimeter towers
  - From towers with track corrections (E-flow type)
  - Using reconstructed objects (jets, e, γ, μ…)
    - Many possible variations for different:
      - object definitions (e.g. jet algorithm)
      - type/level of object corrections
- Open issues
  - Propagating corrections for response to pions and/or jets
  - Corrections for low-P_T tracks (“loopers”)
  - Understanding of unclustered energy, calibration
  - Noise and pileup effects, channel thresholds
- Hence, many studies needed -- help welcome
- For now, we focus at the calorimeter-level definition (using EcalPlusHcalTowers)

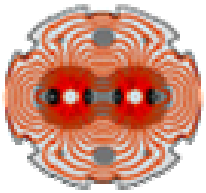
MET Resolution Studies

- Use the same QCD dijet samples as for jet studies
  - ΣE_T range 200 – 8000 GeV
- MET and ΣE_T calculated from calorimeter towers
- Studies of sensitivity to energy cutoffs, parameterization of resolution, work towards E-flow expected in near future



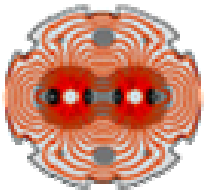


LPC JetMET Plans and Physics TDR



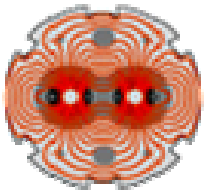
- **Development and support of the jet and missing-E_T software is our major goal – requested by the head of CMS PRS**
  - **Need commitment of software experts in addition to volunteer physicist effort**
  - **The LPC is pursuing the appropriate resources for this task**
- We have already started contributing to several areas that will be part of the Physics TDR, as identified by the PRS JetMET leadership (see backups)
  - Understanding jet response and corrections
  - Understanding MET resolutions
  - FAMOS for physics studies
  - Physics channels: QCD dijets and Z' dijet-resonance search
- We will expand our contributions as the necessary resources become available
  - Calibration and trigger
  - Physics channels that focus on understanding HCAL and JetMET issues (some students already assigned)
    - QCD dijet production and dijet resonance searches
    - SUSY in the jets + MET channel
    - qqH
    - Top, ttH
- Coming soon: a 1-day P-TDR/JetMET/HCAL workshop on November 12 (coordinated by the PRS JetMET group)

Conclusions and Outlook



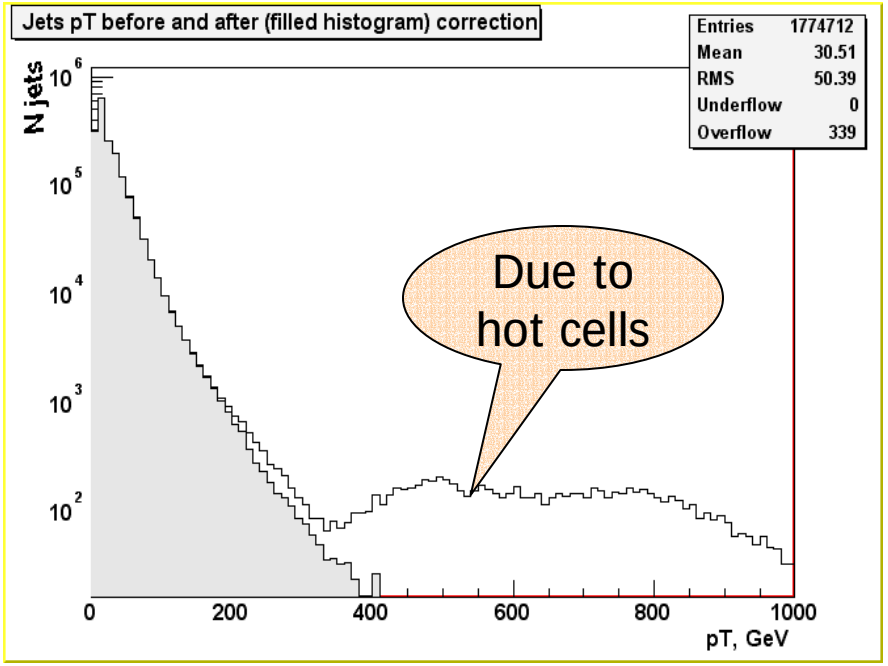
- The LPC JetMET effort is gearing-up strongly
  - ➔ Our expertise in detector issues, software, simulation is rapidly increasing
  - ➔ New people are joining and starting to contribute
  - ➔ Interactions with HCAL and PRS JetMET efforts have opened many avenues for involvement
- Physics TDR is an excellent opportunity to establish ourselves within CMS and to hone the skills
- Have to be ready for Day One
- We need your support, postdocs, students!

Backup Slides

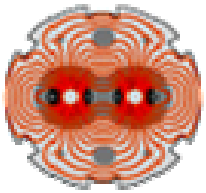


Tevatron Experience with Jets

- Midpoint algorithm is the primary variant; KT algorithm also used
- Adding 4-vectors (E-scheme) preferred to E_T-weighting (E_T-scheme)
  - ➔ But: is it optimal for “bump” searches?
- Splitting and merging essential for physics
- Low-P_T jets affected by detector noise
  - ➔ Various protections developed
- Algorithms have to be robust against underlying event, multiple interactions
  - ➔ KT algorithm appears particularly sensitive
- Resolution improvements using tracks being developed



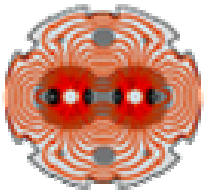
CMS Jet Software: High Level Map



Vertical slice of the jet reconstruction code:

- RecJetRootTree: Produces root tree with jet info
- RecJet: Creates persistent jet objects
- PersistentJetFinder: Calls the jet algorithm to make the jets
- IterativeConeAlgorithm: Example jet algorithm which clusters the constituents (the towers, or tracks, etc.)
- VJetableObject: Class that holds the jet constituents
- VJetFinderInputGenerator: Virtual class to fill list of generic jet constituents (vector of VJetableObjects)
- JetFinderEcalPlusHcalTowerInput: Class to fill list of towers in calorimeter (vector of VJetableObjects with EcalPlusHcalTowers)
- EcalPlusHcalTower: Class for building ECAL + HCAL towers

Examples of Building and Running



TestRecJet.cpp: Program to test use of RecJet by printing out jet η and ϕ

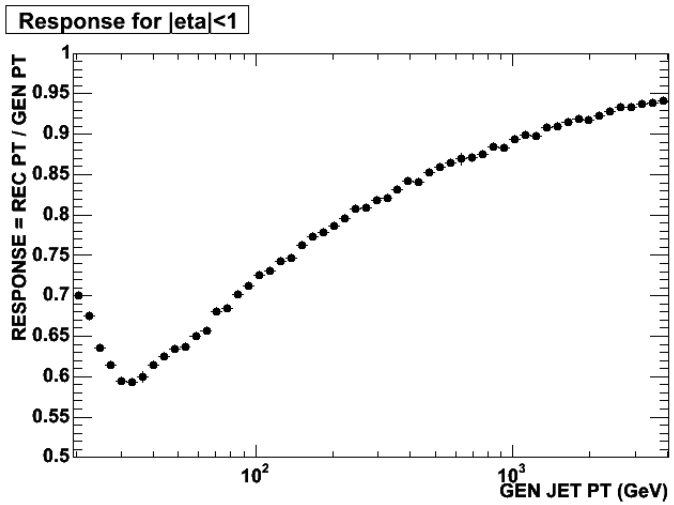
- BuildTestRecJet.csh : Script to compile and link the program on CMS UAF
- RunTestRecJet.csh : Generic script to run the program on CMS UAF
- JobTestRecJet.csh : Script that runs job on specific DC04 dataset (QCD)
- jm03b_qcd_230_300.txt : Output log file for QCD dijets with $230 < P_T < 300$ GeV

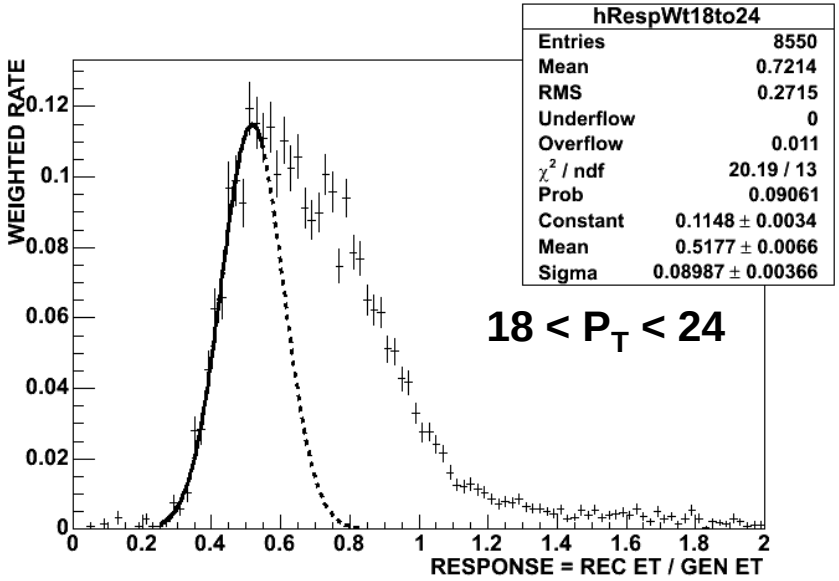
RecJetRootTree.cpp: New code to create root tree with jet information

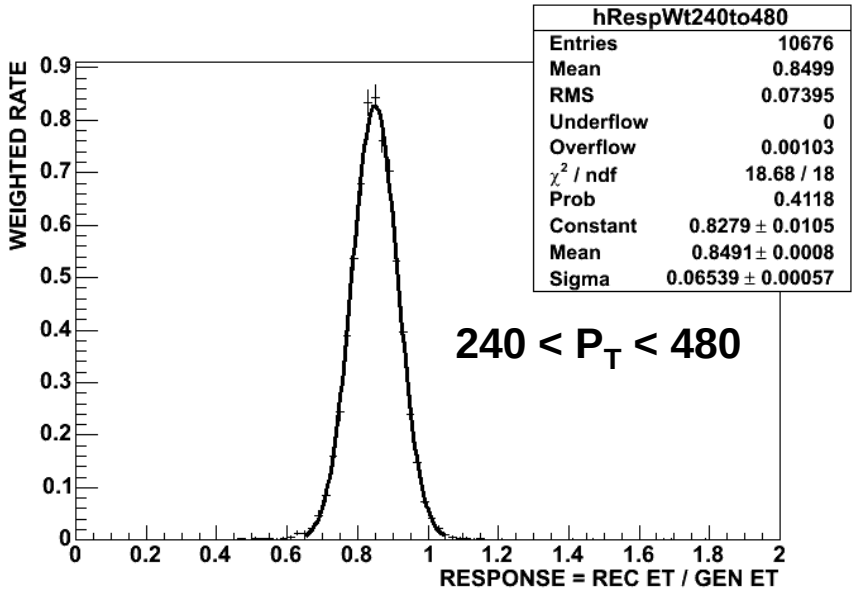
- BuildRecJetRootTree.csh : Script to compile and link the program on CMS UAF
- RunRecJetRootTree.csh : Generic script to run the program on CMS UAF
- JobTestRecJet.csh : Script that runs job on specific DC04 dataset (QCD)
- RootTreeJob_jm03b_qcd_230_300.txt : Output log file
- RecJet.root : Output root tree with 10 events

Jet Response vs. P_T

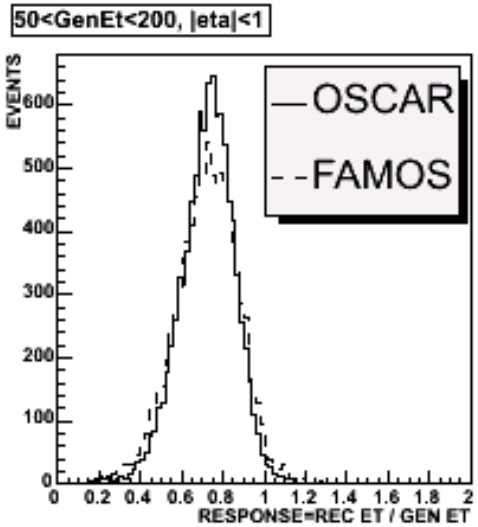
- Response studied using QCD dijet samples, P_T^{Gen} = 15 -- 4000 GeV
- Root trees that just contain generated and reconstructed jets written on CMS UAF at Fermilab
  - ➔ Gen and Rec jets matched if R<0.4
- Response shows Gaussian behavior at high P_T, but deteriorates at low P_T

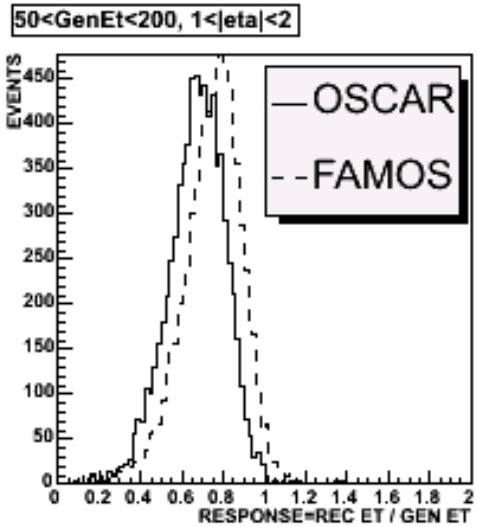


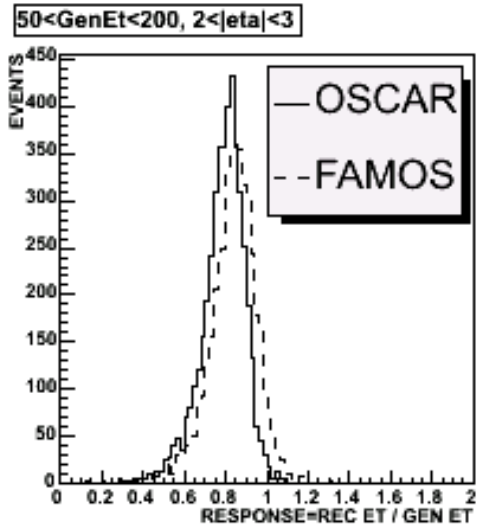


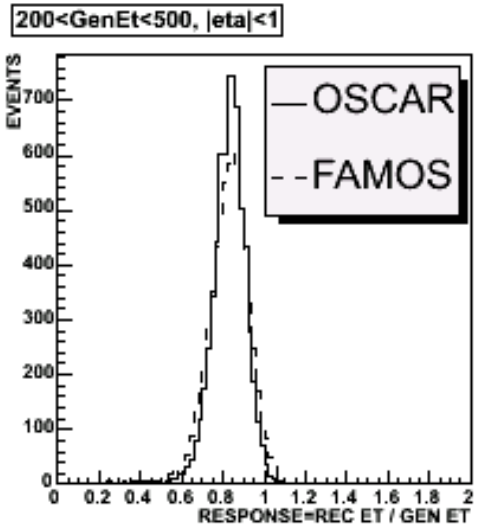


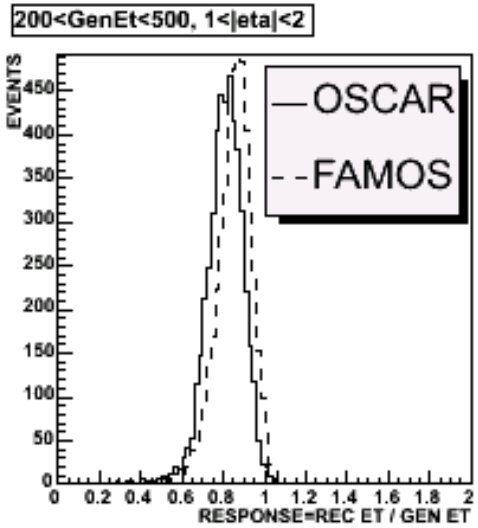
OSCAR/FAMOS: Distributions of Jet Response

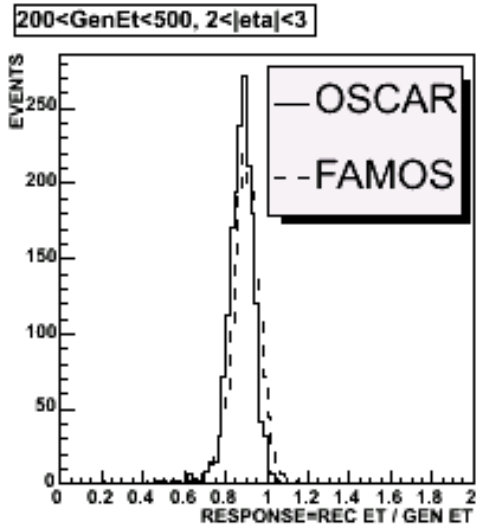






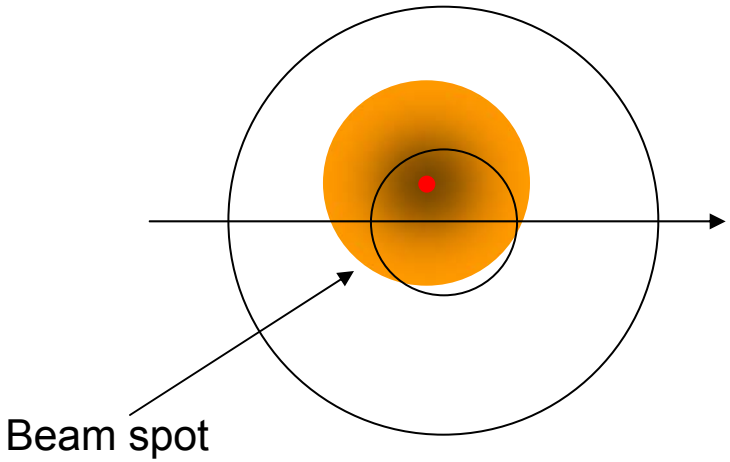


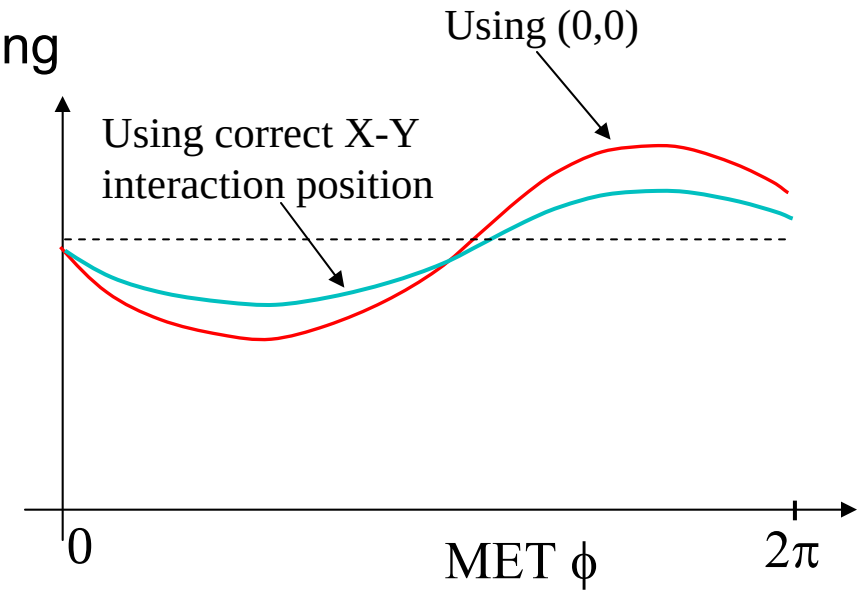




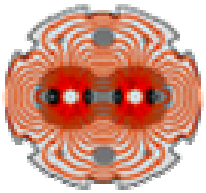
Tevatron Experience with MET

- Great tool for finding detector problems!
  - Removal of hot channels crucial
  - Distributions of METx, METy used to monitor running conditions, declare bad calorimeter periods
- Important issues
  - Propagating corrections for jets and muons
  - Understanding of unclustered energy, calibration
  - Low channel thresholds, large η coverage
- Sensitive to alignment and vertexing





PRS JetMET Plans and Physics TDR



- ***HLT and physics object reconstruction***
  - Development and maintenance of Jet ORCA code
  - Development and maintenance of MET ORCA code
  - HLT event selection
  - Validation of performance
- ***FAMOS***
  - Verification of physics objects
  - Verification of OSCAR/ORCA agreement
  - Event monitoring
  - Analysis examples
  - Interface to jet reconstruction
  - Interface to MET reconstruction
  - Single-particle hadronic shower response
- ***Simulation***
  - **Geometry:** HB HE HO HF
  - Geant-4 shower
  - Geant-4 Cerenkov
  - Pulse shape and timing
  - HO trigger
- ***HCAL Calibration***
  - Radioactive source
  - Library of responses
  - Gamma + jet
  - W from top
  - Jet corrections
  - MET corrections
- ***Data Base***
  - Construction
  - Equipment
  - Configuration
  - Conditions
  - Monte Carlo
- ***Detector Controls***
  - Parameter downloading
  - High Voltage
  - Low Voltage
  - Laser
  - LED
  - Source
  - Jet and MET response tuning
- ***Local DAQ***
  - XDAQ
  - Interface with DCS
- ***Data monitoring***
  - Online monitor
  - Offline monitor
  - Radiation damage
- ***Test beam***
  - RECO code maintenance
- ***Physics TDR analysis***
  - qqH
    - Study of trigger turn-on curves
    - Dilepton, MET and forward tagging jet preselection
    - Lepton + MET + high Pt W hadronic decay + tag jets preselection
    - Jet resolution and energy scale for forward tagging-jets
    - MET resolution
    - Top and multijet backgrounds
    - Top and W + n jet backgrounds
    - Diboson + n jet backgrounds
    - Primary vertex assignment for central jet veto
    - b-ID veto
    - Mass analysis
    - algorithms of high Pt W->qq mass reconstruction
  - Z-prime to jets
    - Study of trigger turn-on curves
    - Jet Response Linearity and Calibration
    - QCD background
    - Dijet mass resolution and background shape determination
    - Centrality and spin analysis
    - Multiple Resonances and large width analysis
  - SUSY
    - Study of SUSY working points for general search
    - Study of trigger turn-on curves
    - MET reconstruction and calibration
    - Jets+Missing energy preselection
    - W/Z+Njet, ttbar and QCD backgrounds
    - Lepton triggering
    - Mass difference analysis
  - QCD
  - Top