Report from the LPC JetMET group

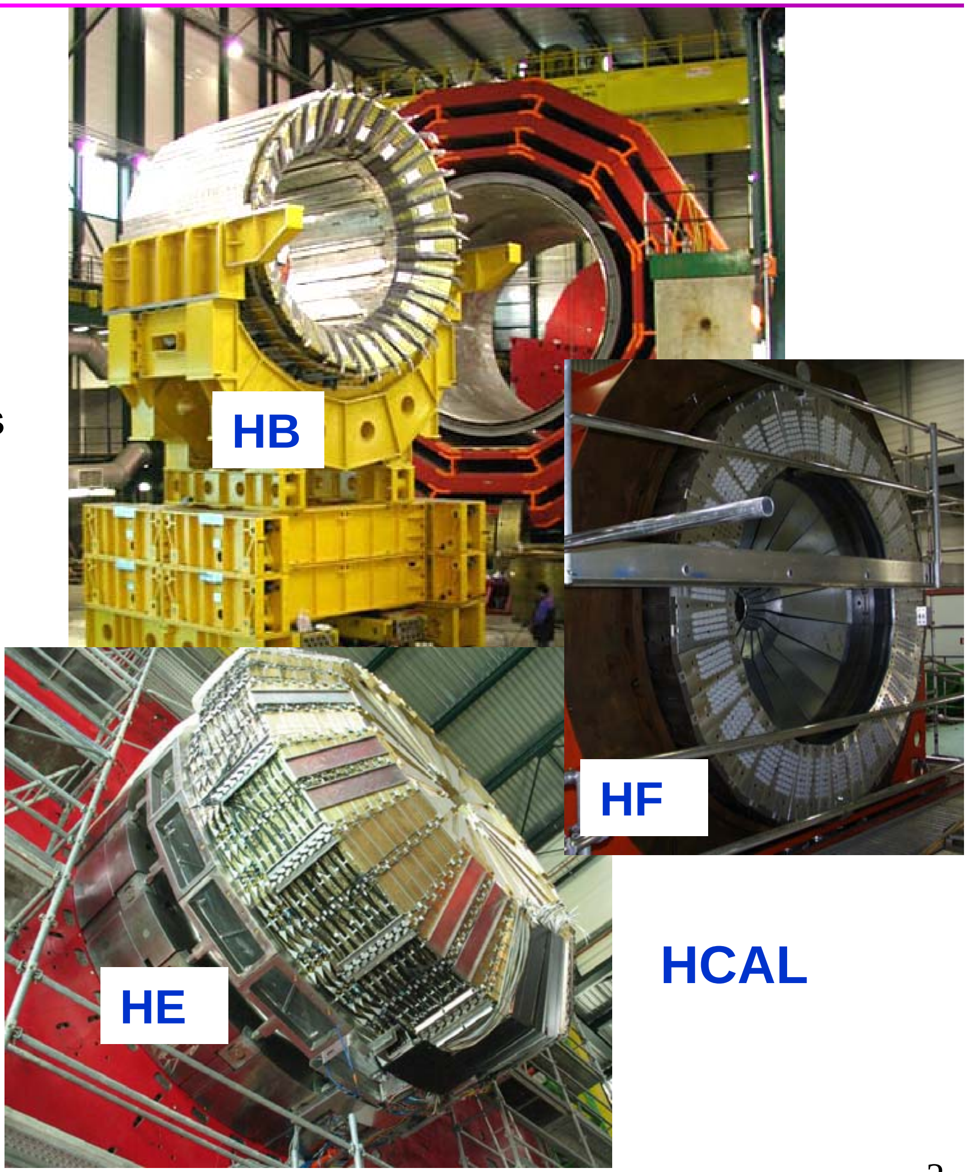
Robert Harris
Fermilab

Marek Zieliński
Rochester

Advisory Council Review of LPC
22 October 2004

Outline

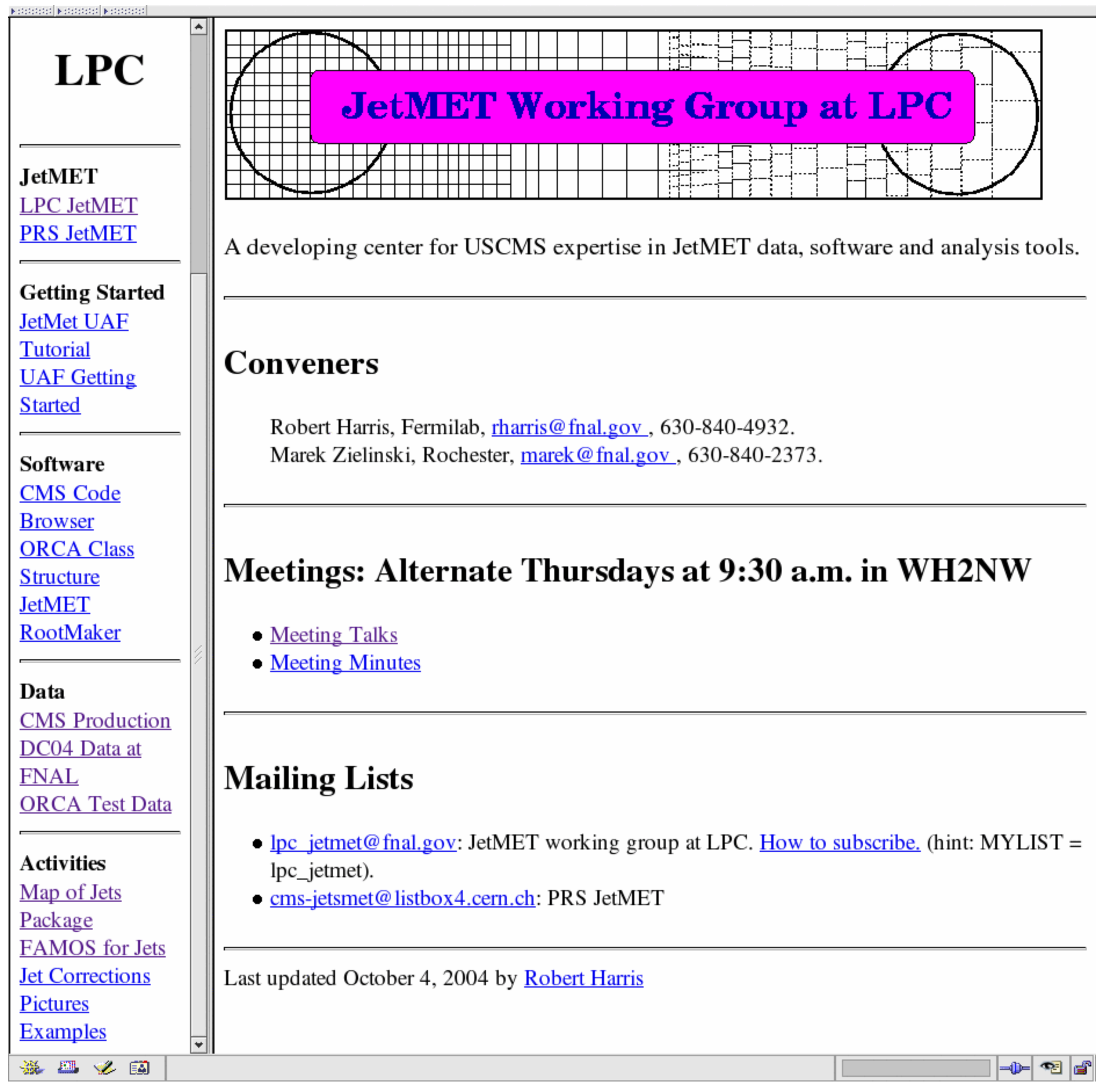
- The LPC JetMET group
  - Goals
  - Members
- Calorimeter Issues
  - Detector aspects
  - Geometry: $\eta-\phi$ map of calorimeter towers
  - Lego display
- Jet studies
  - Jet algorithms and software
  - Analyses:
    - Response
    - Jet Corrections
  - Simulation: OSCAR and FAMOS
- MET studies: resolution,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



HCAL

LPC JetMET Information

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



LPC

JetMET
LPC JetMET
PRS JetMET

Getting Started
JetMet UAF Tutorial
UAF Getting Started

Software
CMS Code Browser
ORCA Class Structure
JetMET RootMaker

Data
CMS Production
DC04 Data at FNAL
ORCA Test Data

Activities
Map of Jets Package
FAMOS for Jets
Jet Corrections
Pictures
Examples

JetMET Working Group at LPC

A developing center for USCMS expertise in JetMET data, software and analysis tools.

Conveners

Robert Harris, Fermilab, rharris@fnal.gov , 630-840-4932.
Marek Zielinski, Rochester, marek@fnal.gov , 630-840-2373.

Meetings: Alternate Thursdays at 9:30 a.m. in WH2NW

- Meeting Talks
- Meeting Minutes

Mailing Lists

- lpc_jetmet@fnal.gov: JetMET working group at LPC. How to subscribe. (hint: MYLIST = lpc_jetmet).
- cms-jetsmet@listbox4.cern.ch: PRS JetMET

Last updated October 4, 2004 by Robert Harris

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 exchanges 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, in addition to the well-established hardware role
- Interacting with other LPC groups

Ongoing LPC JetMET Efforts

- Learning about detectors, JetMET software, simulation
- Calorimeter studies, evaluation/feedback for lego display
- Jet studies
  - Jet energy response and corrections as a function of P_T and η
- MET studies:
  - Resolutions and significance
- Simulation
  - Response to jets and single pions in FAMOS (fast simulation, ~1 s/ev), compared to OSCAR (full G4 simulation, ~10 min/ev)
  - Test/tune the simulation to make it adequate for jet use
    - In coordination with the LPC and CMS Simulation groups

- Aiming for growing and increasingly important role in support and development of jet and missing-E_T software

Ongoing Efforts II - HCAL/Test Beam

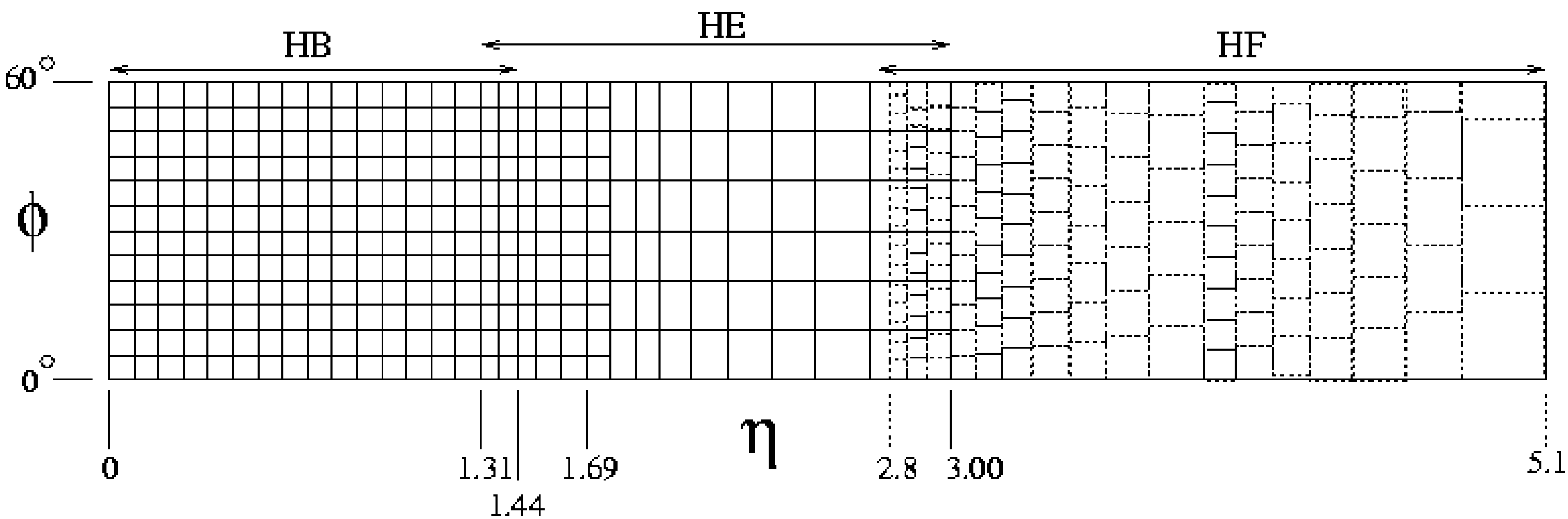
- TB2002-TB2004 analysis -- data taking finished this Monday
  - Extraction of key parameters for detector simulation and event reconstruction
    - Pulse shape, pulse timing, electronics noise, ADC-to-GeV, etc.
  - Checking detector effects
    - Gaps, uniformity, abnormally large signal, etc.
  - Development of algorithms for calibration, monitoring and data validation
  - Test of GEANT4 physics
    - e/π, resolution, longitudinal & transverse shower profile
    - 3--300 GeV beams, with particle-ID (p, K, π, e) below 9 GeV
- Physics benchmark studies ramping up – Goals:
  - Identify issues in event reconstruction and triggering
    - Then 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, HO, HE, HF
    - 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
  - Significant tracker material before the calorimeters (0.2--0.4 λ_0)
  - Significant noise levels (hundreds of MeV/channel)
  - Event pileup (~3 events/crossing even for low luminosity)
  - Inside high magnetic field (affects light yield, sweeps low P_T particles…)
- Challenge for algorithms to maximize performance

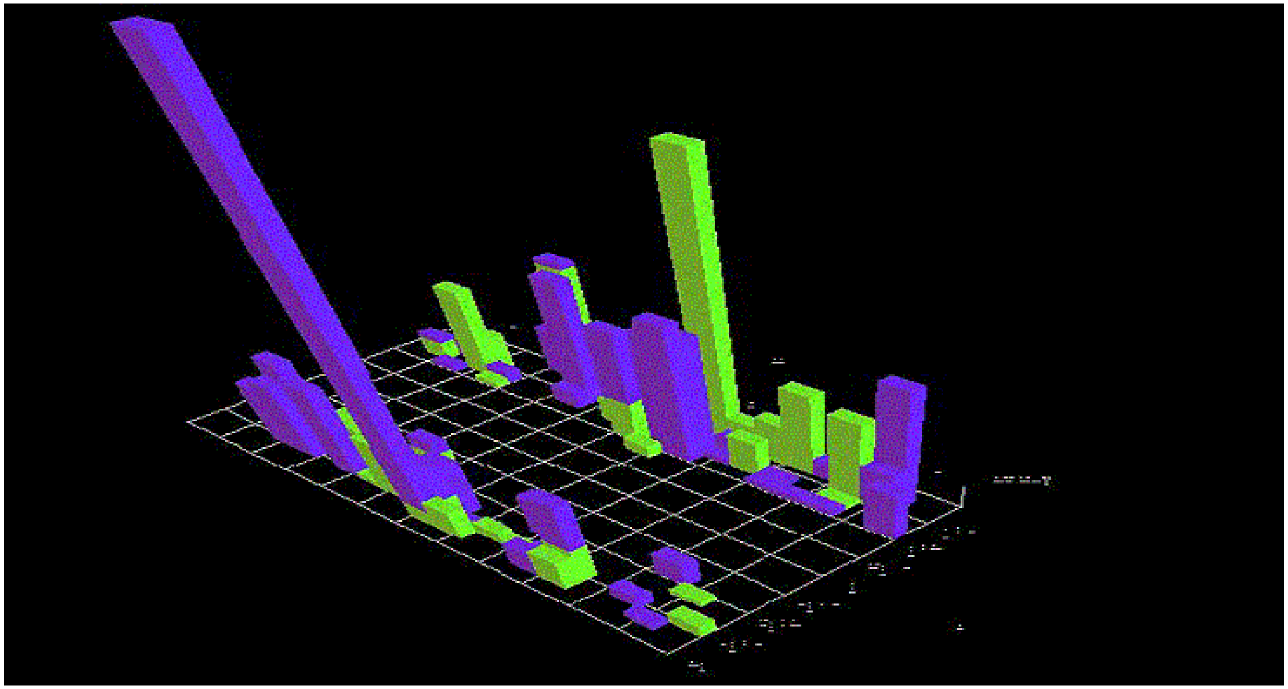
Calorimeter: Geometry

- Understanding of basic geometry crucial for code development and interpretation of simulations
  - Verifying geometry in software vs. actual construction
- η-ϕ map of HCAL towers
  - Constructed a map from information found in HCAL TDR, updates ongoing
    - Connection to HCAL group 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 more realistic 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 parameter D_{cut}
    - KtJetAlgorithmNjet
      - Forces the final state to decompose into N jets
- A more comprehensive “vertical” slice of the jet reconstruction code, from DST to root-tuples, is included in the backups

Examples of Building and Running

- We provided basic examples to help new users to start contributing (available from webpage)
  - Tool to test 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 specific DC04 dataset (QCD)
    - Typical output logfiles
    - A small output root-tree

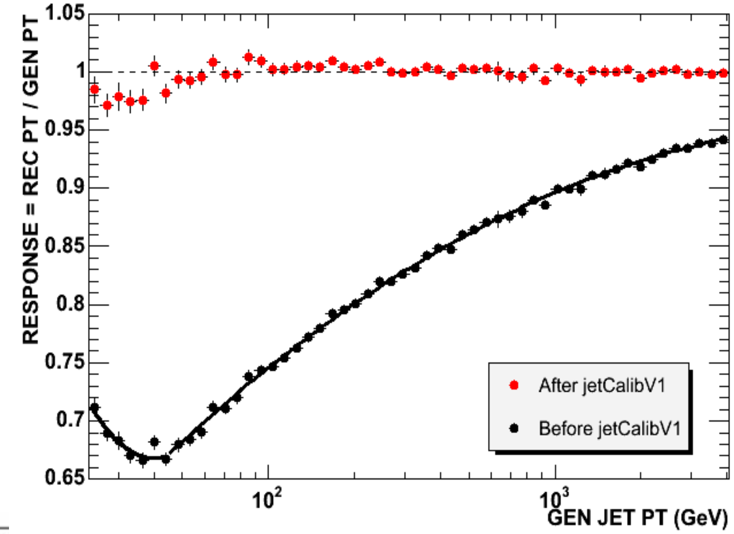
- Our webpage includes additional resources and links to full-blown JetMET tutorials, UAF information, software tools and Monte Carlo datasets

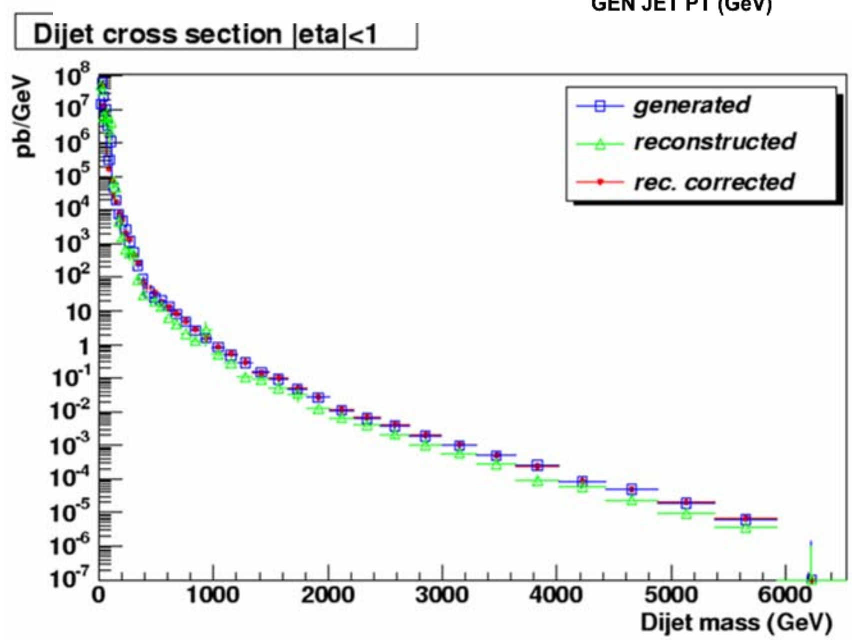
Studies of Jet Response and Corrections

- Work has been requested by PRS JetMET group
  - Correction software completed in ORCA and available to CMS
- P_T of reconstructed jets 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
- Goal: provide software to correct the reconstructed jet P_T back to the particles in the jet
  - For now, considering jet algorithms that use only calorimeter information
  - Current study is based on the knowledge of "Monte Carlo truth"
  - Need to develop data-based jet calibration methods, using response to tracks and P_T-balancing in dijet, γ-jet and Z-jet systems
- We determined, as a function of P_T and η
  - Response = Reconstructed Jet P_T / Generated Jet P_T
  - Correction = 1 / Response

Jet Corrections and Closure Tests

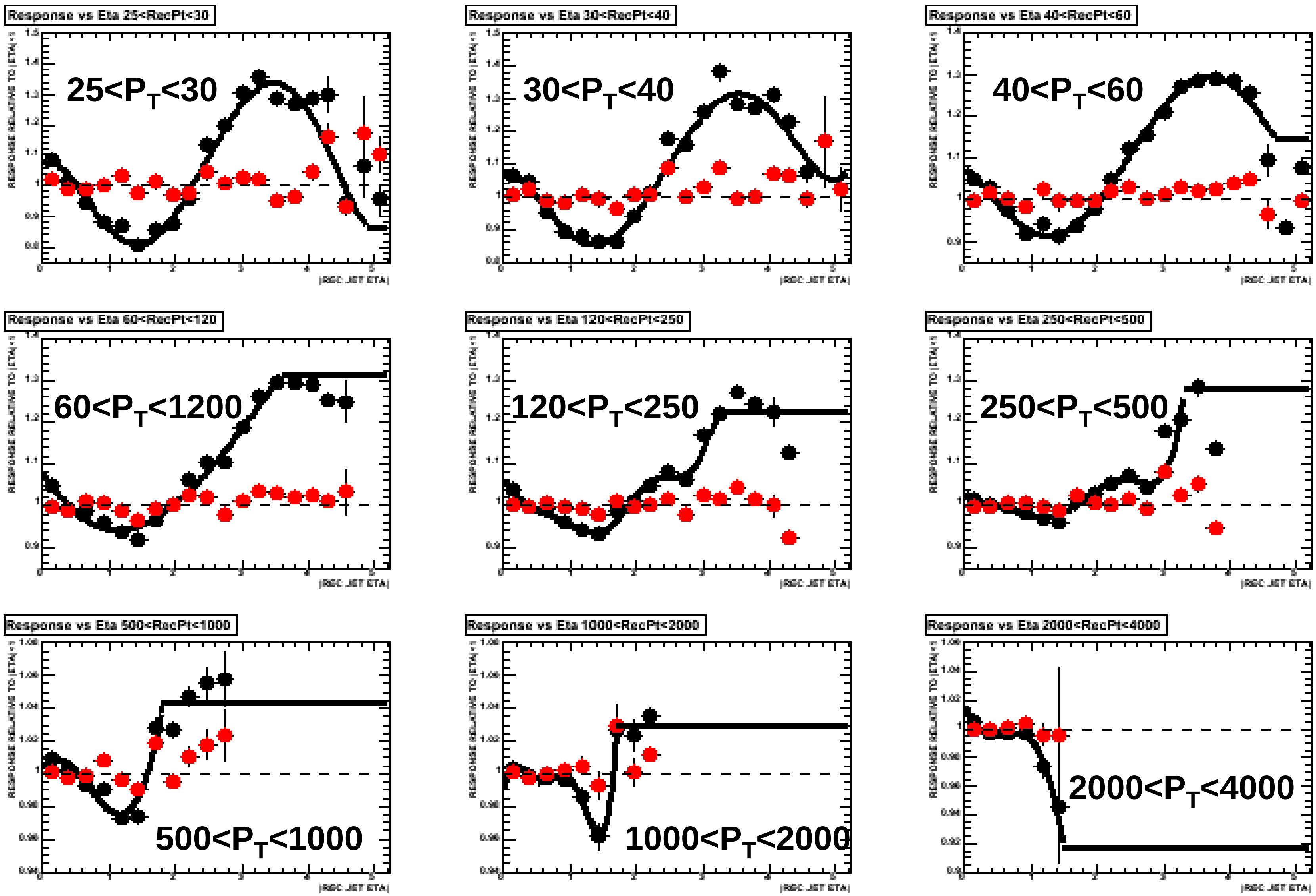
- Response studied using QCD dijet samples, P_T^{Gen} = 15 -- 4000 GeV
- The measured average response was parameterized with functional forms vs. jet P_T and η
  - For Iterative Cone, R=0.5, tower E > 0.5 GeV, lum = 2×10^{33} $cm^{-2}s^{-1}$
- Applying parameterized corrections:
  - Is correcting back to particle-jets before pileup
  - Makes original response functions flat
  - Correction good to ~1% for Rec Jet P_T > 30 GeV, $|\eta| < 1$
  - Correction good to ~2% vs. η
  - Another test: seems to work OK for the reconstructed dijet mass spectrum
- Corrections currently implemented in the JetMetAnalysis package of ORCA





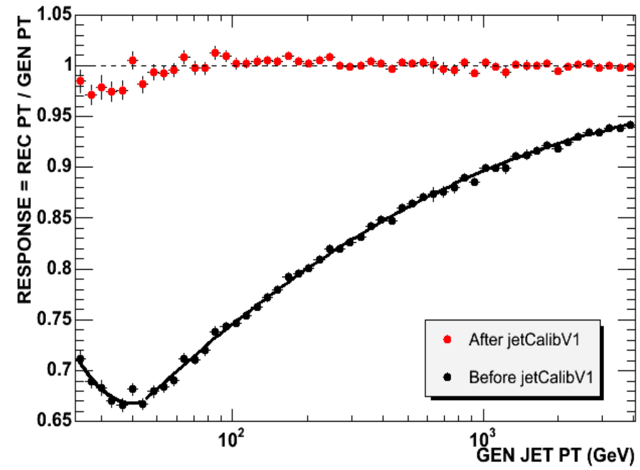
Jet Response vs. η (Relative to $|\eta| < 1$)

- Before Corrections
- After Corrections

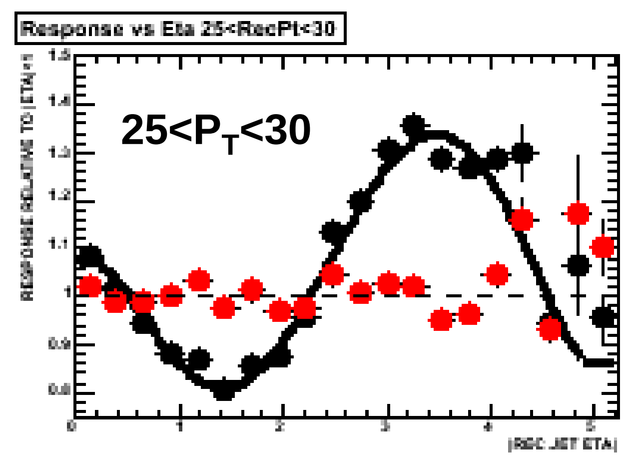


Discussion of Jet Response vs. P_T & η

- Response vs. P_T
  - Response rises with increasing P_T for P_T > 40 GeV
    - As expected from non-linear response of calorimeters to pions
  - Response rises with decreasing P_T for P_T< 40 GeV
    - Thought to be a result of contributions from noise and of tails in the resolution of response



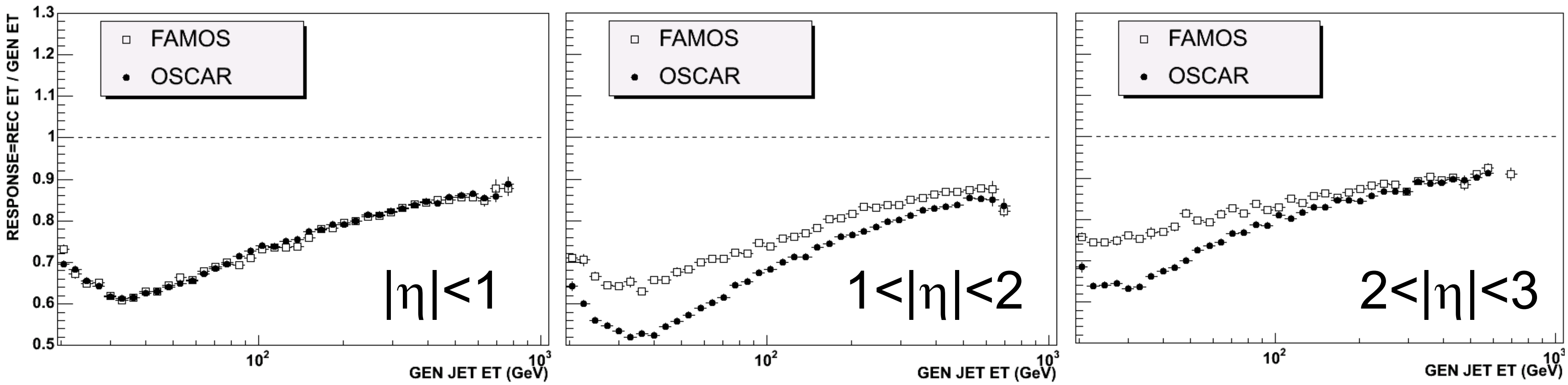
- Response vs. η
  - In Barrel: decrease in response with increasing η at low P_T
    - Noise contribution to jet energies is ~several GeV; its influence on P_T diminishes with increasing η
  - In Endcap: increase in response with increasing η
    - Interpreted as due to improved linearity with increasing E, and to migration of soft spiraling particles into the Endcap
  - In Forward: higher level of response than in Barrel or Endcap
    - Thought to 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 seek to understand the current status of FAMOS for jets
  - How does it work?
  - Does it accurately reproduce mean jet response?
  - Does it accurately reproduce jet resolution?
- First step – done
  - Compare FAMOS and OSCAR for jet response and resolution
  - Compare the basic parameters in FAMOS to those for testbeam
- Next steps:
  - Improve the FAMOS parameters, tune to OSCAR
  - Port CMSJET/GFLASH implementation of fast showering
  - Deadline for tuning of HCAL in FAMOS is December 2004 for Physics TDR

Mean Jet Response vs. P_T and η



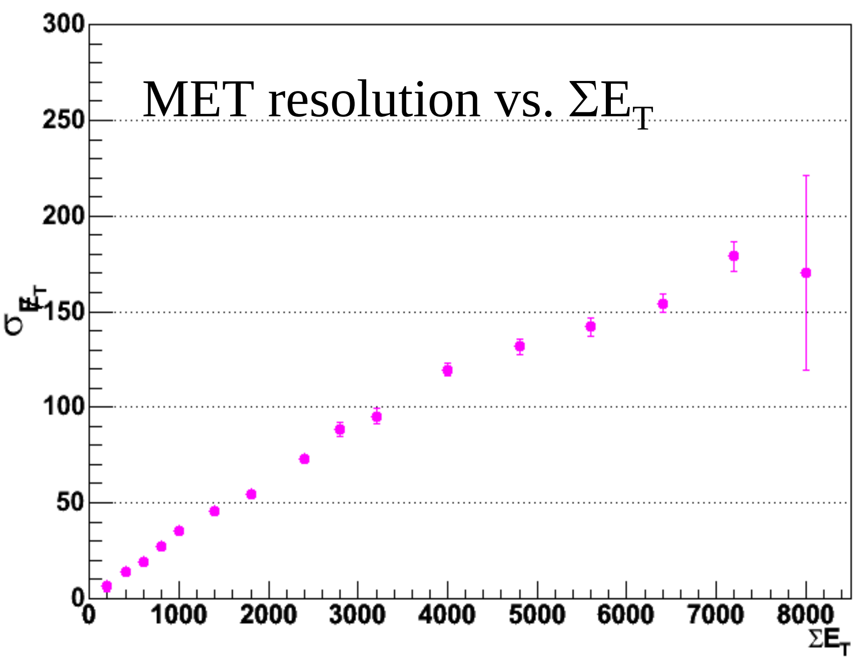
- Features of FAMOS / OSCAR response comparisons:
  - Both FAMOS and OSCAR responses increase with P_T for P_T > 30 GeV
    - As expected from improving linearity at higher E
  - FAMOS response agrees well with OSCAR for $|\eta|$ < 1
  - FAMOS response is higher than OSCAR for $|\eta|$ > 1, needs tuning
    - FAMOS has up to ~20% higher response at low P_T
- Distributions of response also in reasonable agreement (see backups)

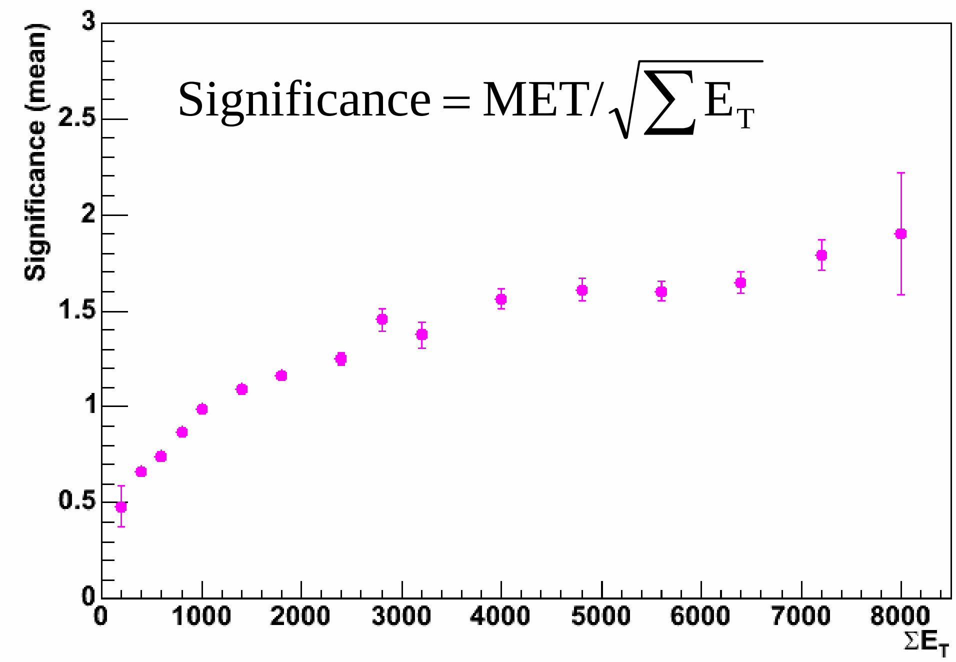
MET Reconstruction

- Several levels of MET reconstruction
  - From calorimeter towers
  - From towers with track corrections (E-flow type)
  - Using reconstructed objects (jets, e, γ, μ…)
    - This involves many possible variations for different:
      - object definitions (eg. Jet algorithm)
      - type/level of corrections (μs, tracks, pileup, jet calibration…)
- Important issues
  - Propagating corrections for pions, jets and muons
  - Corrections for low-P_T tracks ("loopers")
  - Understanding of unclustered energy, calibration
  - Channel thresholds, noise, pileup
- 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





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LPC JetMET Plans and Physics TDR

- Development and support of the jet and missing-E_T software is our major goal
  - Need the 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: dijet mass for QCD 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 JetMET/HCAL/P-TDR workshop on November 12, 2004 (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!

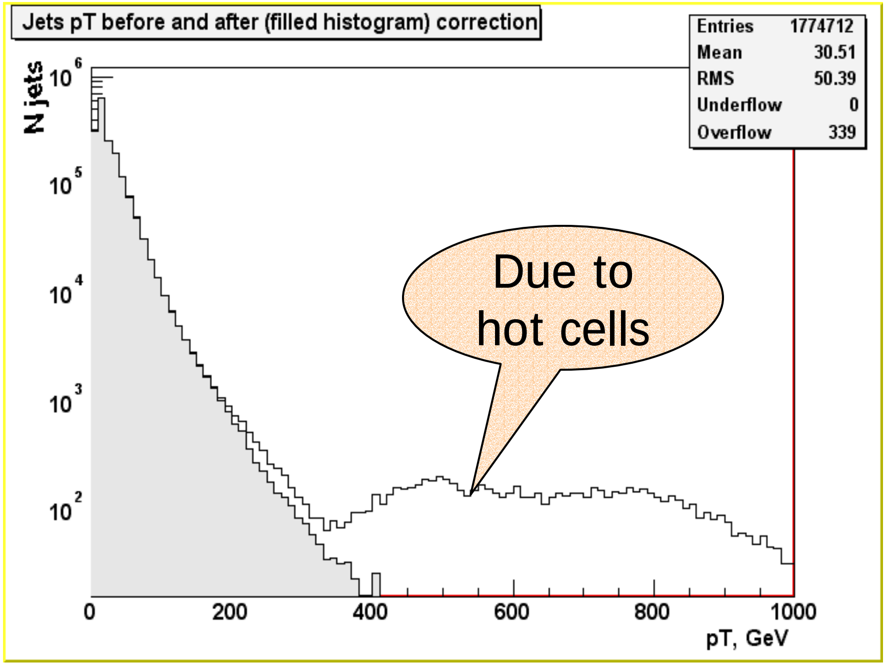
Backup Slides

General Goals

- Form a center at Fermilab for USCMS expertise in JetMET
  - Data
    - Where it is, how to get it, how to analyze it
  - Software
    - Understanding and contributing to the Jet, MET and calorimeter code
    - All levels, from the reconstruction to the root tree and beyond
  - Analysis Tools and Techniques
    - Simulations, Event Displays, Jet Corrections, etc.
- Work in coordination and cooperation with PRS JetMET group
- Help prepare USCMS for analysis of first CMS data
  - Understand LHC phenomena involving jets and/or MET
  - Be ready for possible discovery of new physics phenomena involving jets and/or MET

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: Persistent jet object
- 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

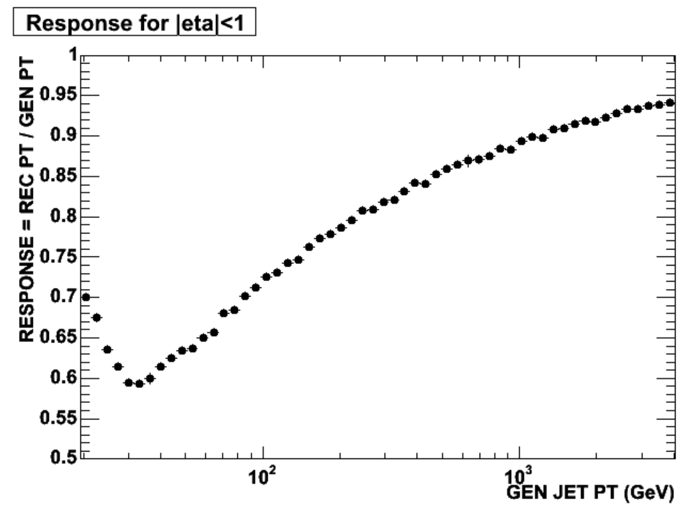
- BuildTestRecJet.csh : Script to compile and link the program on CMS UAF
- RunTestRecJet.csh : Generic script to run the program on CMS UAF
- JobTestRecJet.csh : Script that runs job on specific DC04 dataset (QCD)
- jm03b_qcd_230_300.txt : Output log file for QCD dijets with $230 < P_T < 300$ GeV

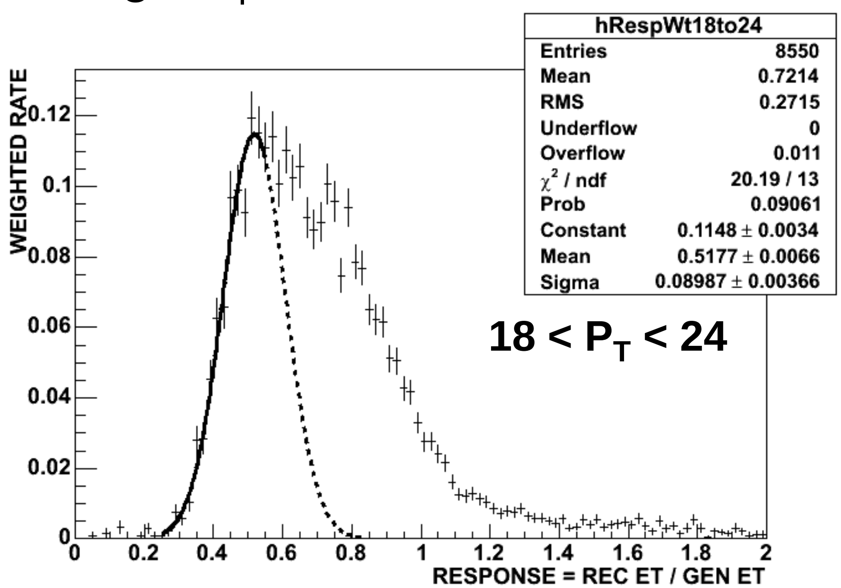
RecJetRootTree.cpp: New code to create root tree with jet information

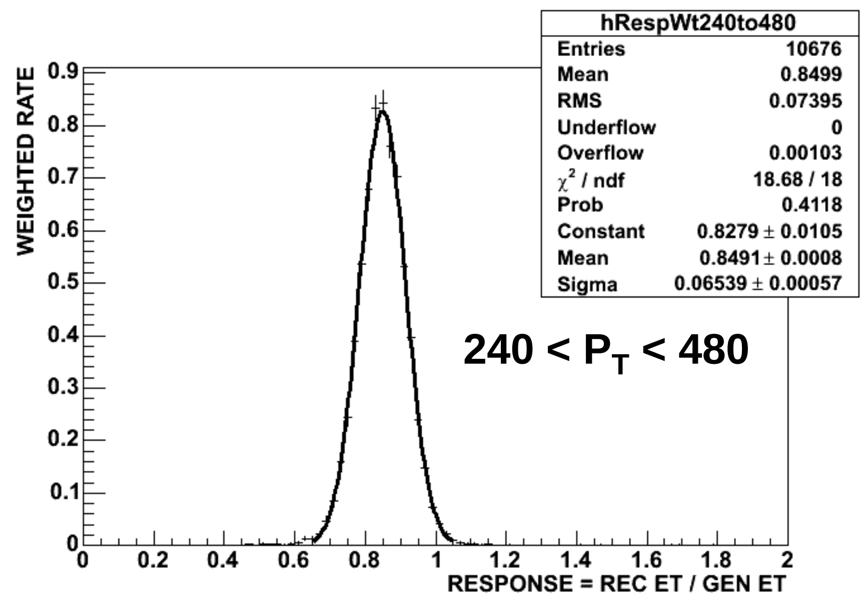
- BuildRecJetRootTree.csh : Script to compile and link the program on CMS UAF
- RunRecJetRootTree.csh : Generic script to run the program on CMS UAF
- JobTestRecJet.csh : Script that runs job on specific DC04 dataset (QCD)
- RootTreeJob_jm03b_qcd_230_300.txt : Output log file
- RecJet.root : Output root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

Jet Response vs. P_T

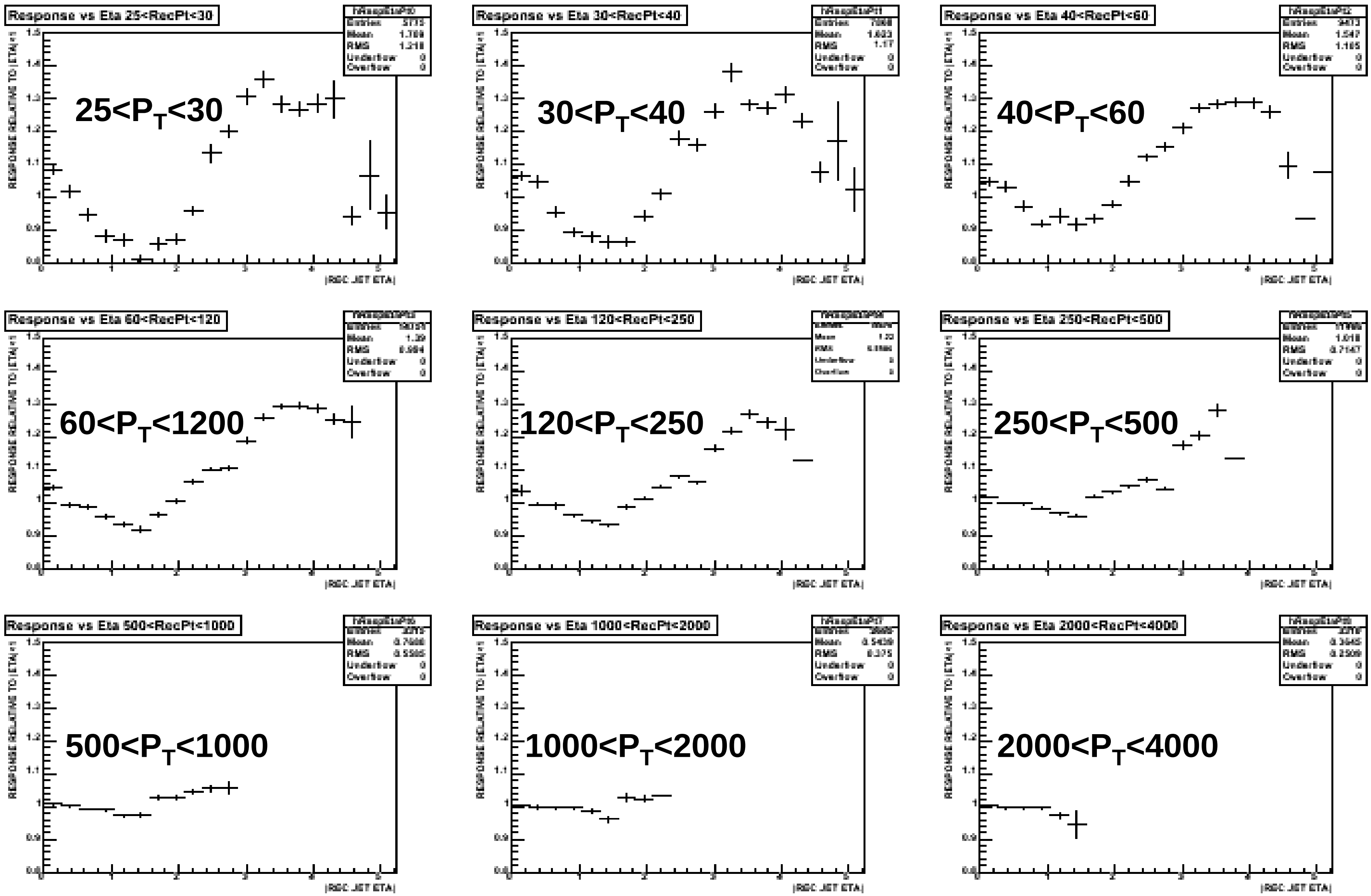
- Response studied using QCD dijet samples, P_T^{Gen} = 15 -- 4000 GeV
- Root trees that just contain generated and reconstructed jets written on CMS UAF at Fermilab
  - ➔ Gen and Rec jets matched if R<0.4
- Response shows Gaussian behavior at high P_T, but deteriorates at low P_T







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



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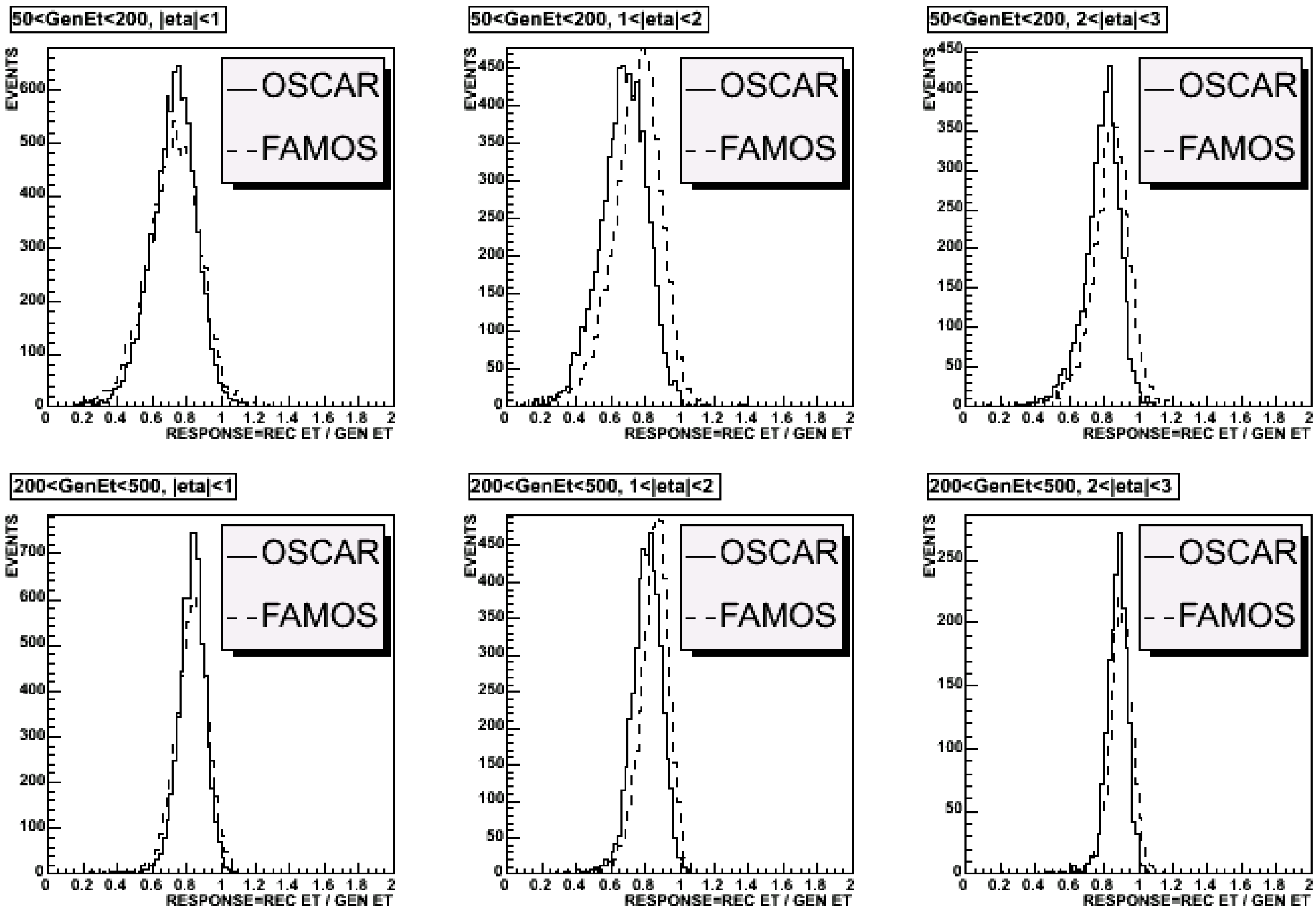
Distributions of Jet Response



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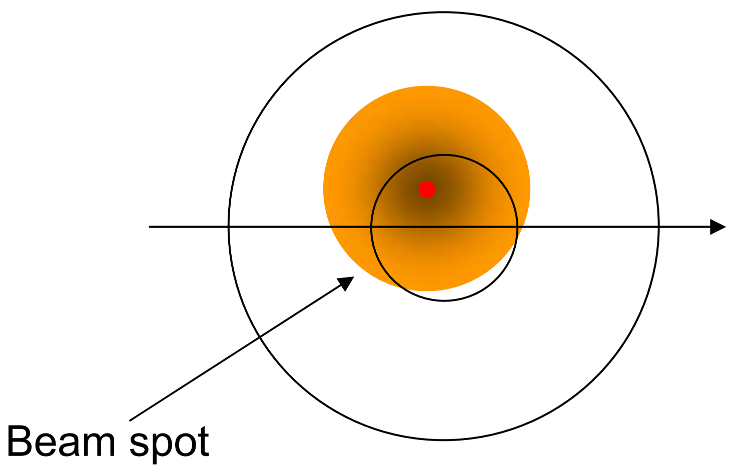
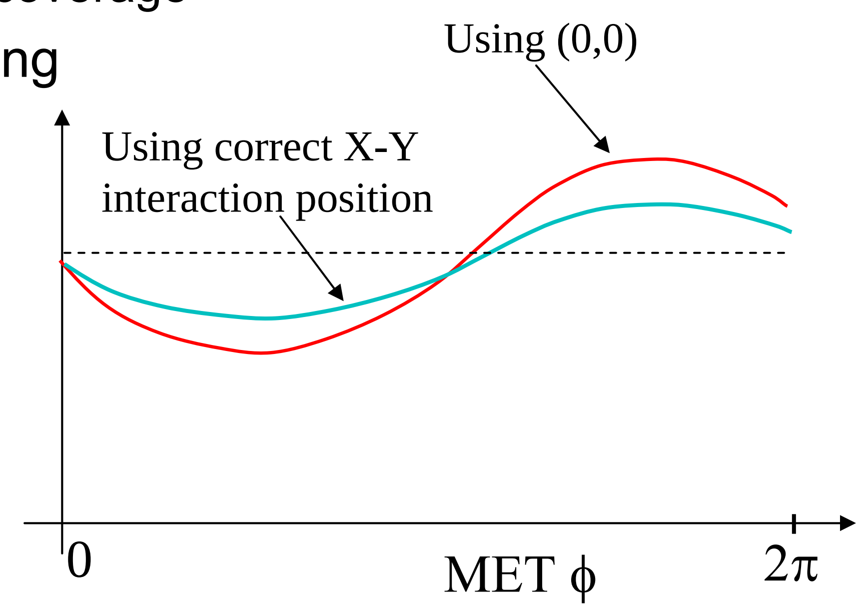
Tevatron Experience with MET

- 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