Precision Calibration of the DØ HCAL in Run II

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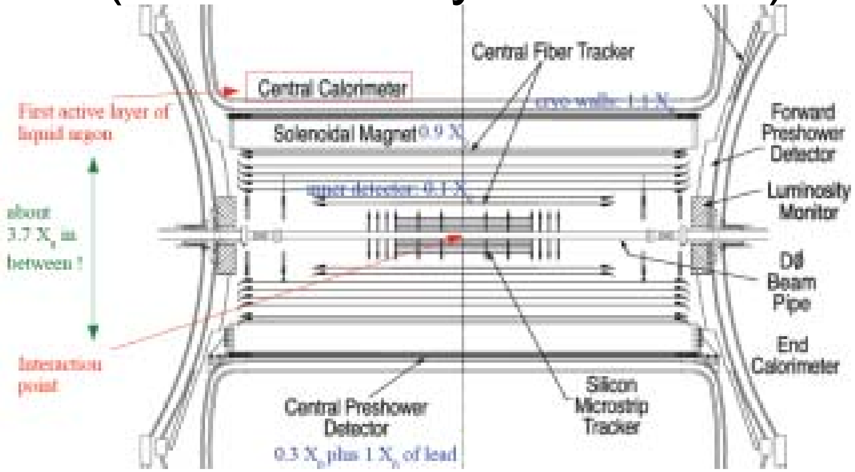
Precision Calibration of the DØ HCAL in Run II

- Motivation and Overview
- Calibration of the DØ HCAL
  - ϕ-intercalibration
  - η-intercalibration
- Isolated pion studies

DØ calorimeter calibration in Run II

- Significant changes for the Run II upgrade:
- Reduction of charge integration time from *2.2μs* to *260ns*
  - Replacement of big parts of the readout electronics in Run II
  - Enhanced sensitivity to the finite mechanical precision of the CAL
    - Positioning of the readout cards in the LAr gaps
    - Possible signal board bending
    - Variations of the width of the Uranium plates
- More dead material in front of the CAL (non-uniformly distributed)
  - Pre-shower detectors
  - Solenoid
  - Fiber tracker
  - Silicon vertex detector
- Amount of dead material depends significantly on angle of incidence



➡ Need *in situ* CAL Run II calibration with the final detector setup

In situ DØ CAL calibration: Overview

- Factorize (roughly) into two parts:
  - Calibration of the calorimeter electronics
  - Calibration of the device itself

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Electronics calibrated using pulsers

- Aim: pulsers are a powerful tool, both for debugging and calibration of the readout electronics
  - Identify technical problems in the electronics, e.g. dead channels
  - Correct for channel-by-channel differences in electronics response
- Principle: inject known signal into preamplifier and equalize readout electronics response
  - Do this separately for the gains x1 and x8
- Among other things gives handle on the non-linearities in the electronics response

In situ DØ CAL calibration: Overview

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Calibration of the device itself

  - First: Calibration of the EM CAL
  - Second: Calibration of the HCAL
- Determine energy scale (i.e. multiplicative correction factor), if possible per cell
- 1st: ϕ-intercalibration to reduce the number of degrees of freedom
  - Use special triggered Run II data
- 2nd: η-intercalibration to get access to the remaining degrees of freedom, as well as the absolute scale for the EM CAL
  - $Z \rightarrow e^+e^-$ for the EM CAL and QCD dijet events for the HCAL

Calibration of the EM calorimeter

- ϕ-intercalibration: equalize the response in ϕ, same method as was used for the HCAL (with different data), see later…
- η equalization and absolute scale:
  - Once ϕ degree of freedom is eliminated, amount of *Z* events is sufficiently high to absolutely calibrate each intercalibrated η ring
  - Write reconstructed *Z* mass as: $m = \sqrt{2E_1E_2\left(1-\cos\theta\right)}$

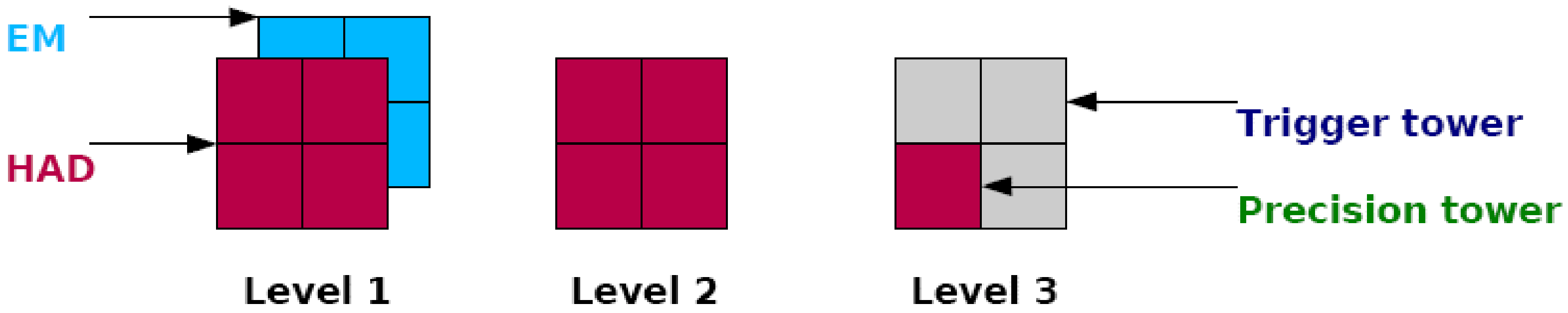
    E_i are the electron energies and θ is the opening angle from tracking
  - The electron energies are evaluated as: $E = E^{raw} + K\left(E^{raw}, \vec{\alpha}\right)$

    Raw energy measurement from the calorimeter

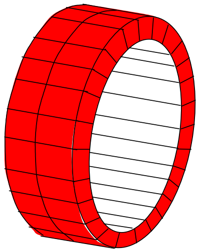
    Parameterized energy-loss correction from detailed detector simulation
  - With the raw cluster energy: $E^{raw} = \sum_{(\text{all cells})} c_{ieta} \cdot E'$
- Determine the set of calibration constants c_{ieta} that minimize the experimental resolution on the *Z* mass and gives the correct (LEP) measured value

Calibration of the HCAL: ϕ-intercalibration

- Due to the unpolarized Tevatron beams physics is ϕ symmetric at DØ
  ➡ Any ϕ dependence must be the result of instrumental effects
- Energy flow method: at a given η bin of the CAL measure the density of calorimeter objects above a given E_T threshold as a function of ϕ. Apply multiplicative calibration factors in each ϕ region in such a way that the candidate density becomes flat in ϕ
- Trigger: collect events with a trigger that was specially designed for this purpose. Data taken during normal physics running
  - Level 1: at least one trigger tower with a total (EM+HAD) E_T > 5 GeV
  - Level 2: require 5 GeV in the hadronic section of the trigger tower
  - Level 3: require a precision tower with E_T > 7 GeV matched to above



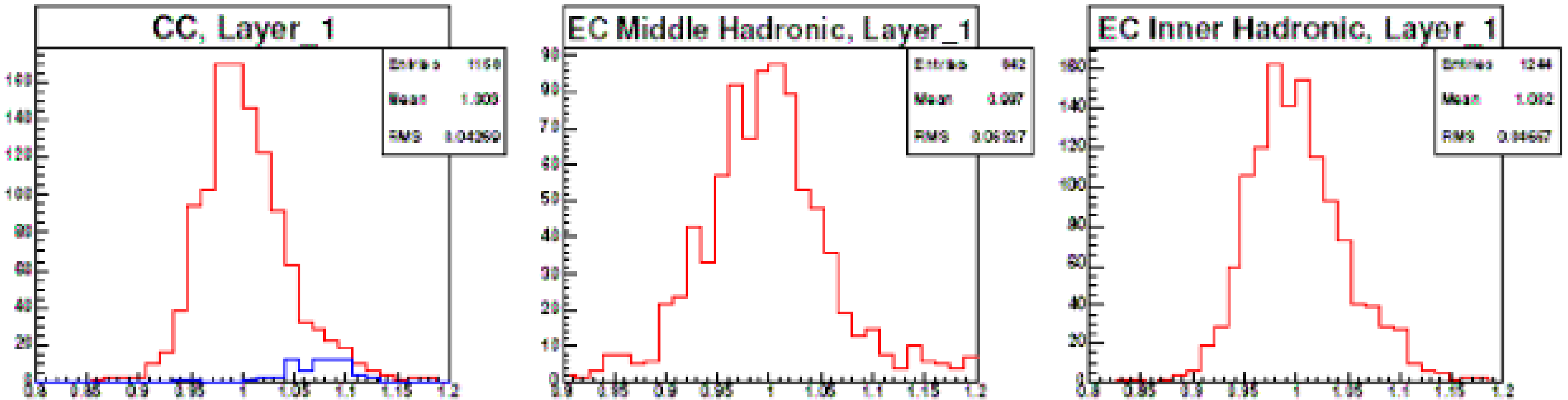
ϕ-intercalibration: Method



- First of all: Study data quality. Separate failures in readout electronics from gain miscalibrations
- Calibration on tower and layer level
- Count events in CAL towers above some E_T cut. Vary the cut so that each tower at given η gives the ϕ averaged number of events. Ratio of cut values at given ϕ and starting one gives tower calibration constants
- Intercalibrate cells inside the tower: Layer calibration constants
  - Energy fraction distributions in ϕ are compared to the average for each layer
  - Compute individual layer χ_i^2's and minimize $\chi_{\text{all}}^2 \equiv \sum_i \chi_i^2$ using **`Minuit`**
- Iterate procedure of layer and tower calibration until stability is reached
- Final ϕ-intercalib. constants products of layer and tower constants

ϕ-intercalibration : Results

As an example: spread of calibration constants for the 1st HCAL layer

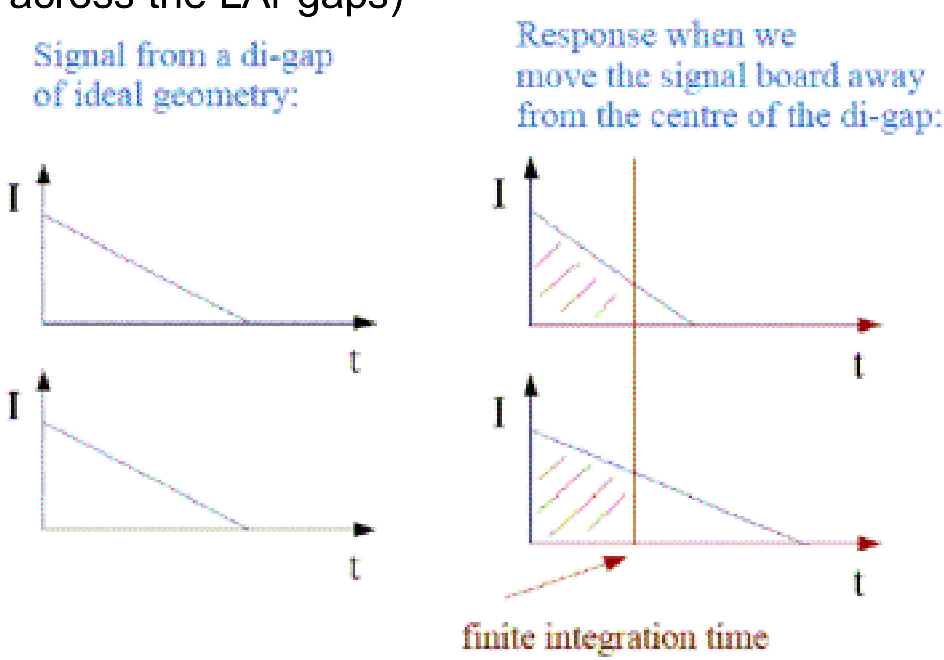


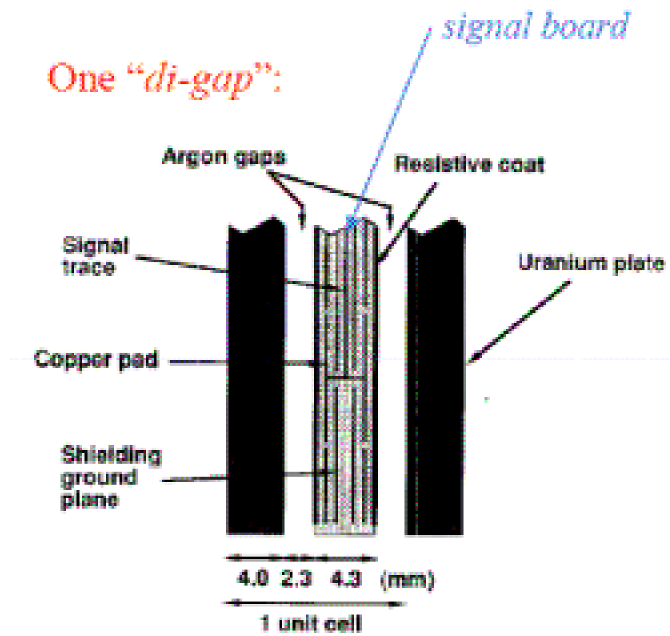
$|\eta|<1.0$ $1.0<|\eta|<1.8$ $1.8<|\eta|<2.8$

- Constants mainly in the range of 0.90-1.15. RMS at the order of 0.05
- Higher η and problematic layers (recognized at data quality check) lead to higher constants
- Similar constants for all HCAL layers
- Error estimation was done with a MC method: generate toy simulations of the data with known miscalibrations and compare to the fitted calibration constants of our calibration procedure.
- The central CAL is calibrated at the order of 1%, for high η it is a few %

Dominant effect for the spread of constants

- Energy response of the modules is less uniform than it was in Run I
- Dominant reason is the short integration time in Run II. It amplifies the effect of the finite precision of the calorimeter modules
  (In Run I, the integration time was essentially “infinite” on the time scale of the drift time across the LAr gaps)

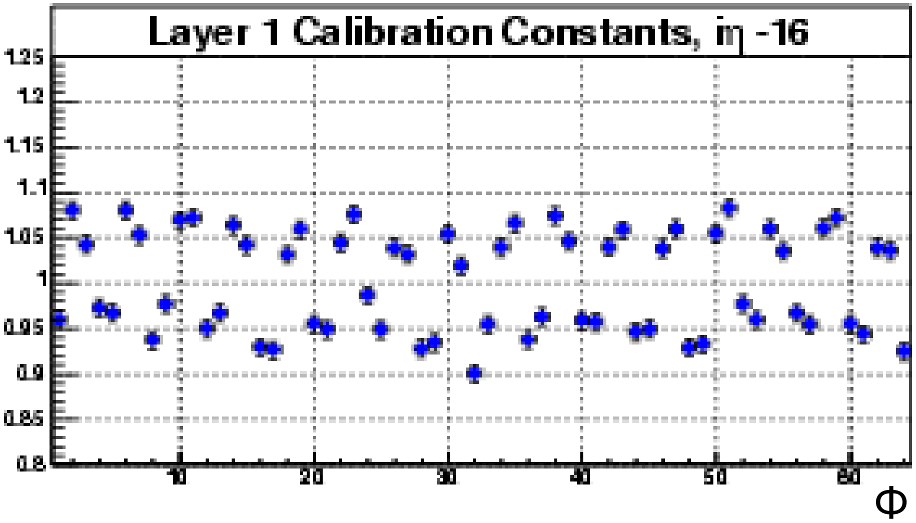


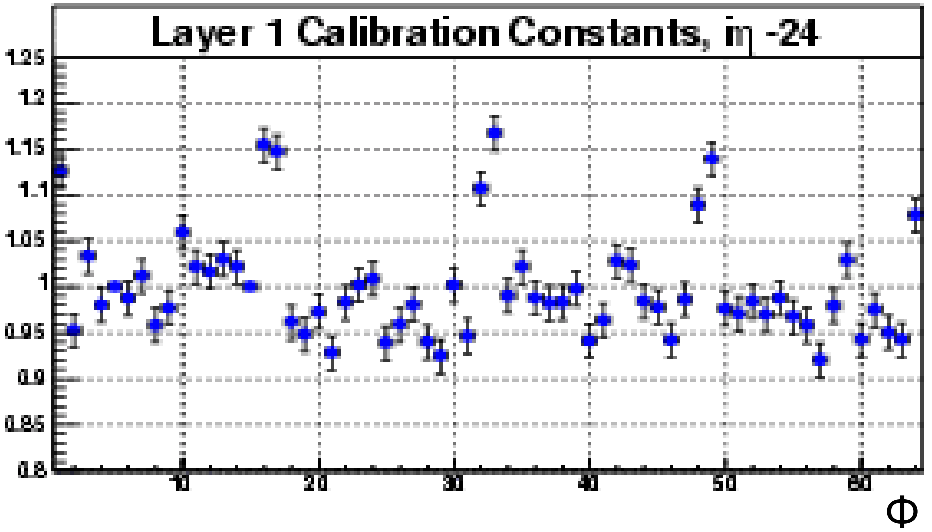


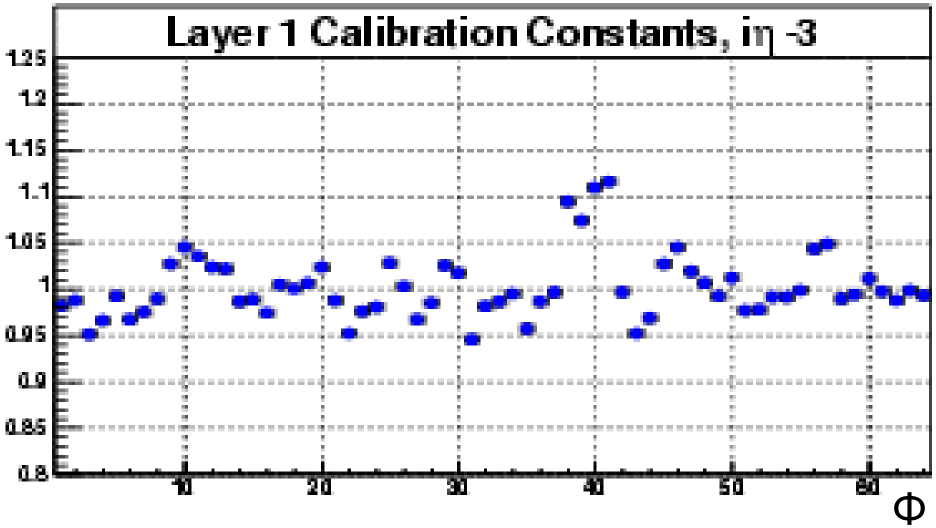
Electron drift time across the 2.3mm gap: ~450 ns. Charge integration time: ~260ns in Run II
~2.2μs in Run I

- ϕ-intercalibration accounts for these charge collection effects

Characteristics of non-uniformities







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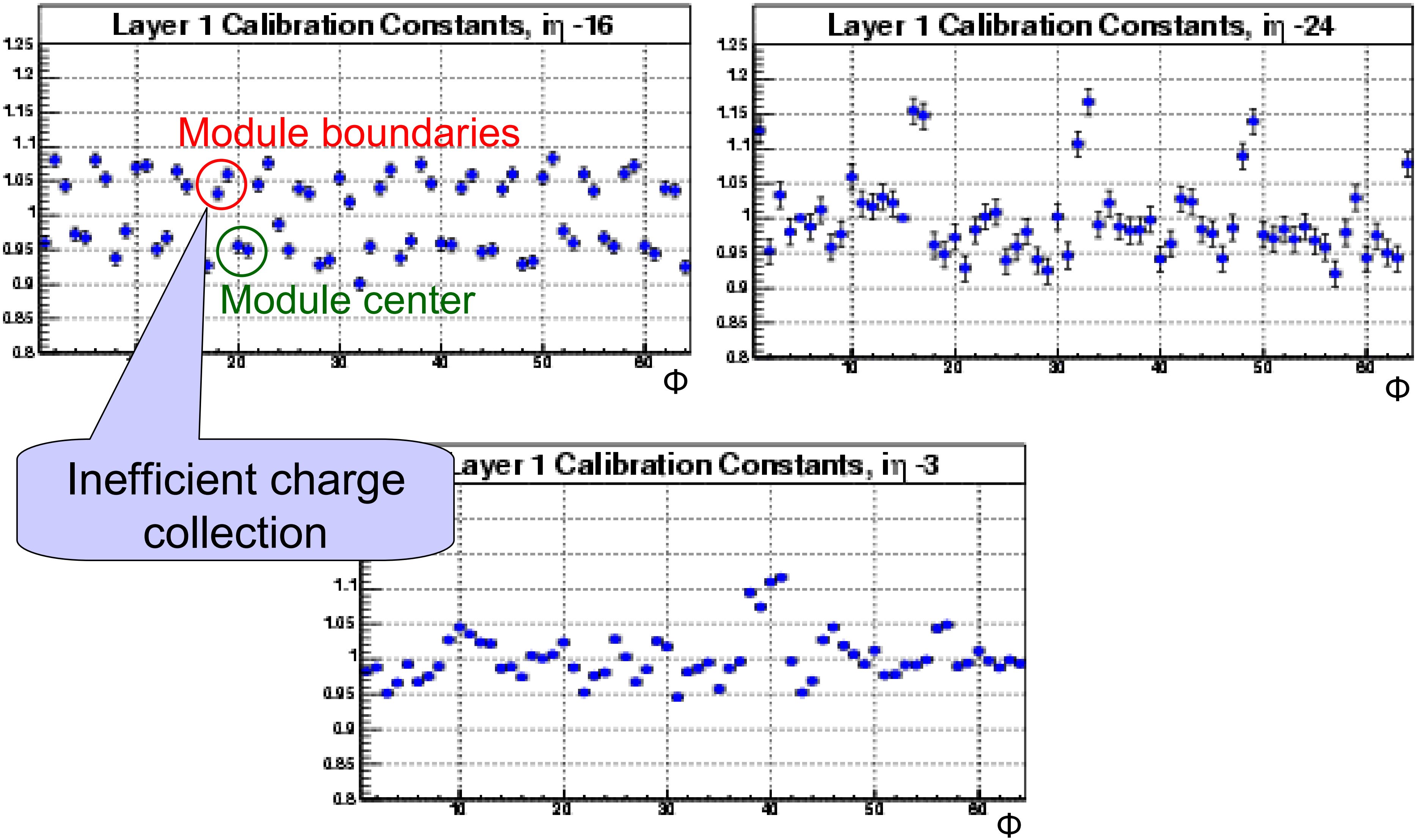

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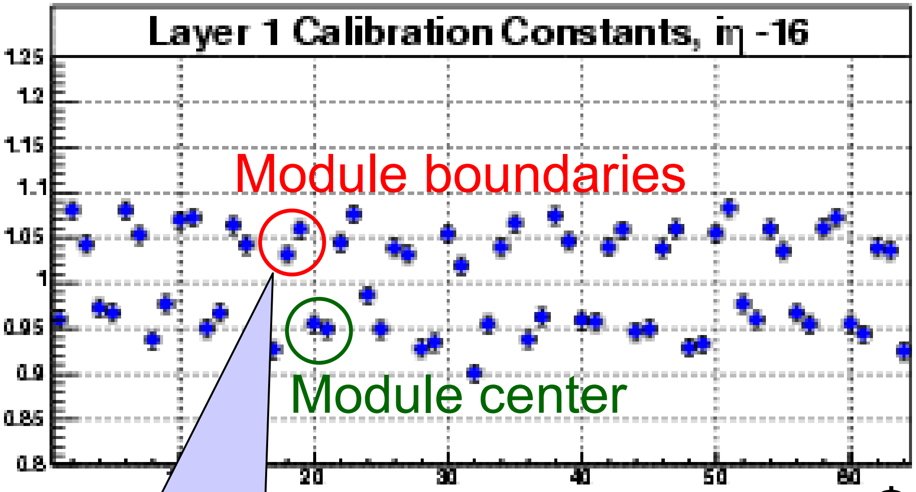
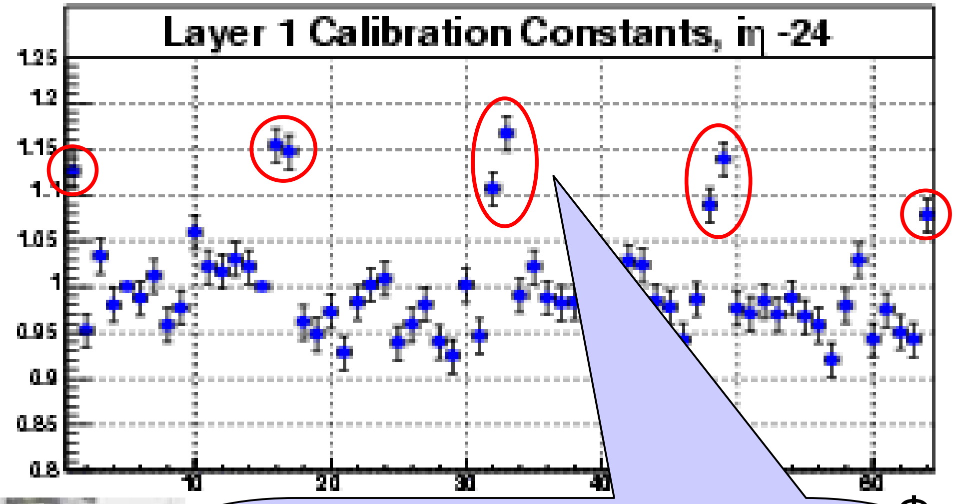
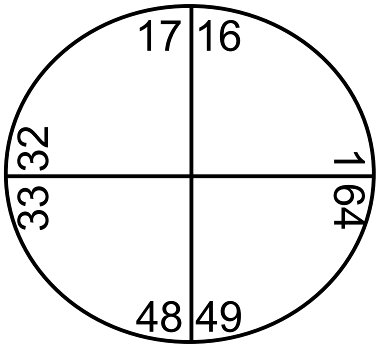




Inefficient cha
collection

Signal boards and absorption layers mounted from half circles



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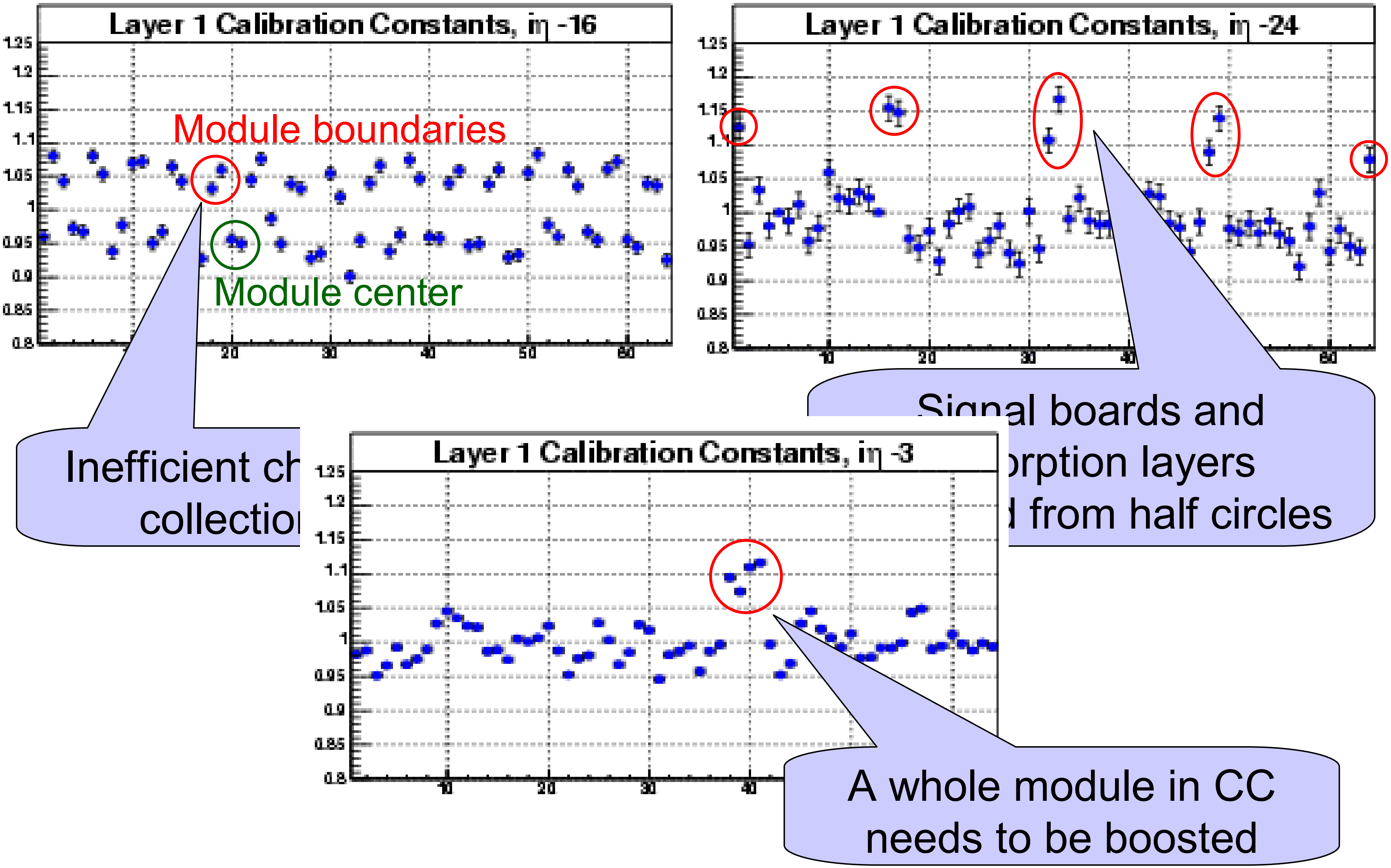


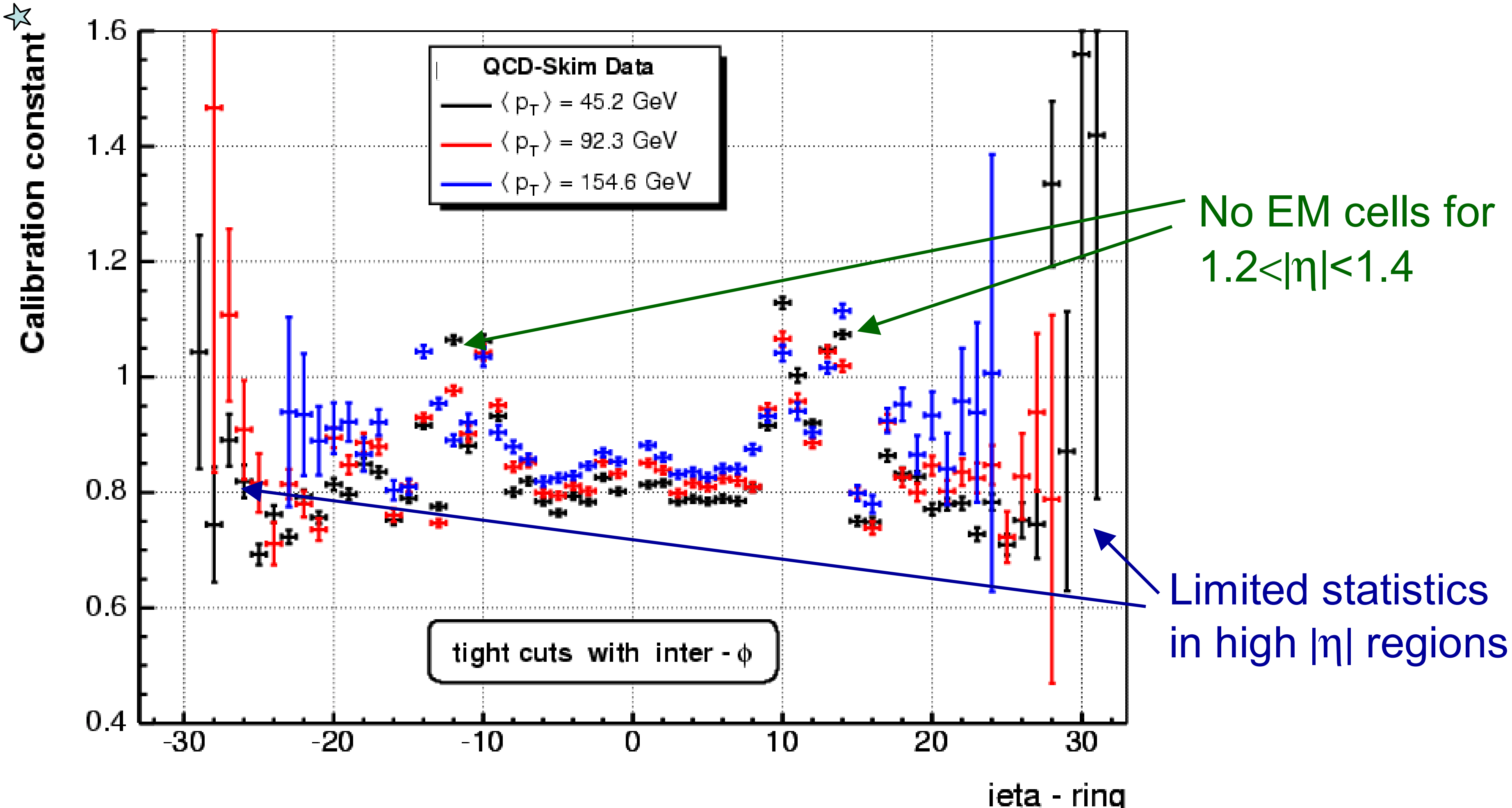
Next: η-intercalibration

- Determine an overall calibration factors for each η ring
  - 64 constants from $-3.2 < \eta < 3.2$
- EM layers are calibrated, hadronic ϕ-intercalibration is applied
- Aim: determine relative weight between EM and HCAL for the best jet energy resolution
  - Necessary consequence: jet response will be non-linear
  - But jet response of this CAL is always non-linear regardless of the weights. Energy-dependent Jet Energy Scale deals with this
- Fraction of energy deposited in the HCAL will rise with the energy

➡ No single optimal constants for all energies

  - Default constants are optimal for jets of ~45 GeV which satisfies the vast majority of physics program at DØ
- Method: use QCD dijet events and minimize the total missing p_T fraction of the events by weighting the HCAL cells within the jets
  - Select only well reconstructed back-to-back two jet events and require an average jet p_T above the trigger threshold

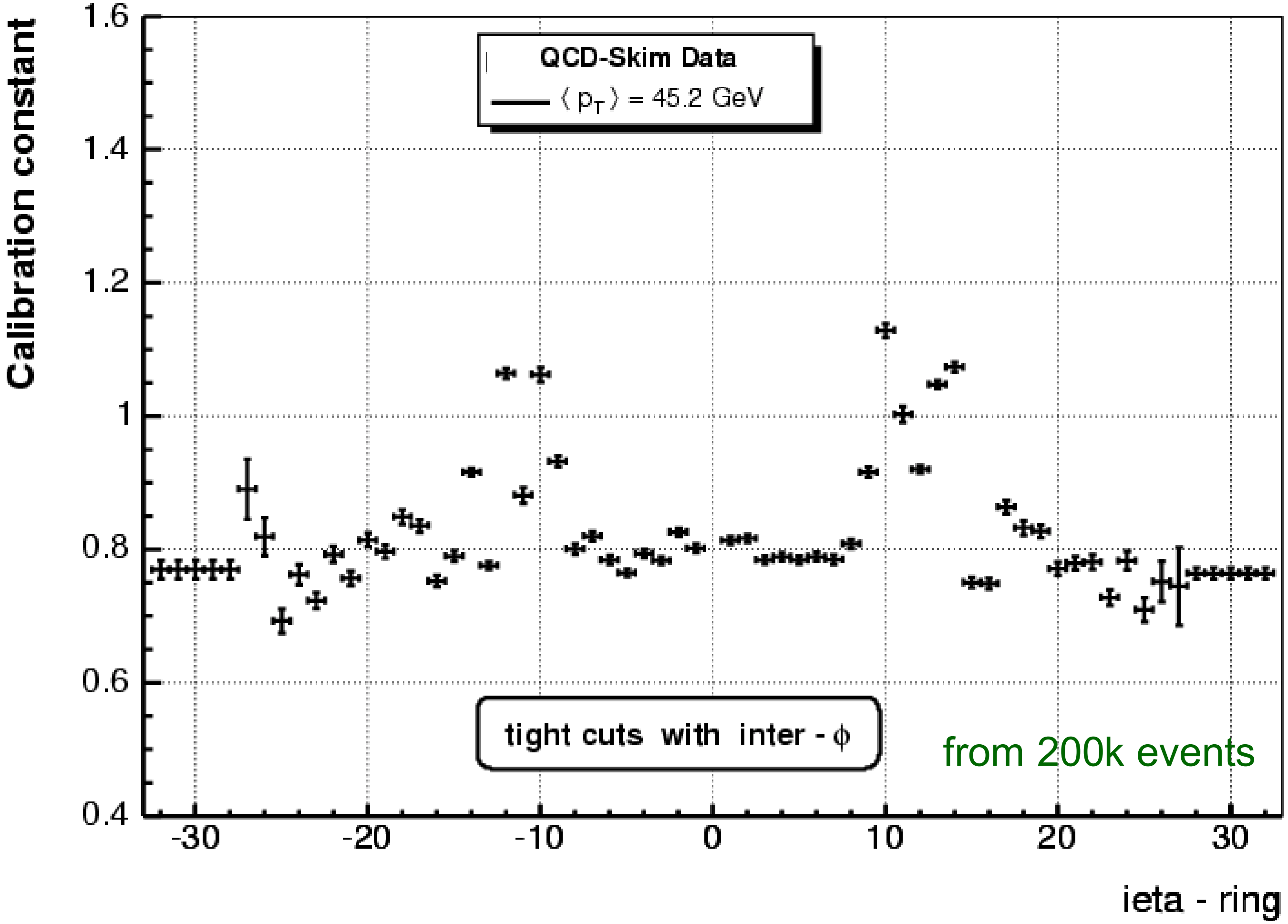
η-intercalibration: Results



- Calibration constants rise with p_T
- There was no appreciable dependence on the jet cone size

☆ constants are on top of the older ones which roughly reproduced the right sampling fractions

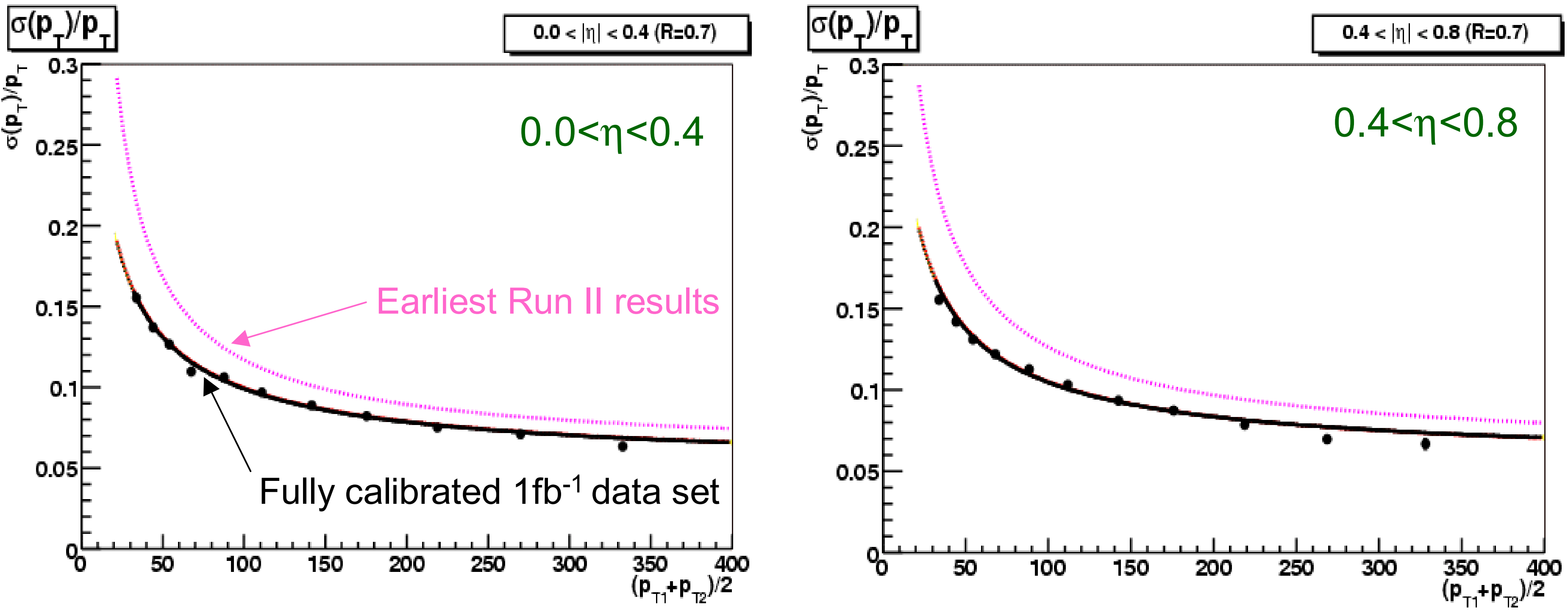
η-intercalibration: Results



- Final calibration constants chosen for $<p_T>=45$ GeV
- Correction factors in the regions $2.0<|\eta|<2.7$ are stable,
  - ➡ extrapolate the mean value of this range to higher η values

Improvement on the jet resolution

- The p_T resolution were re-determined using dijets and the same $1fb^{-1}$ sample to account for the improvements due to the hadronic calibration and Jet Energy Scale
- Significant improvements in the central region



Isolated pion studies: Goals and motivations

- Quantify, understand and possibly further improve the response and resolution of the CAL to hadrons
- Significant changes to the hardware and readout in Run II. Non-uniform distribution of dead material is difficult to mimic in test-beam studies
- The definite understanding of the single pion response has to come from studies *in situ*

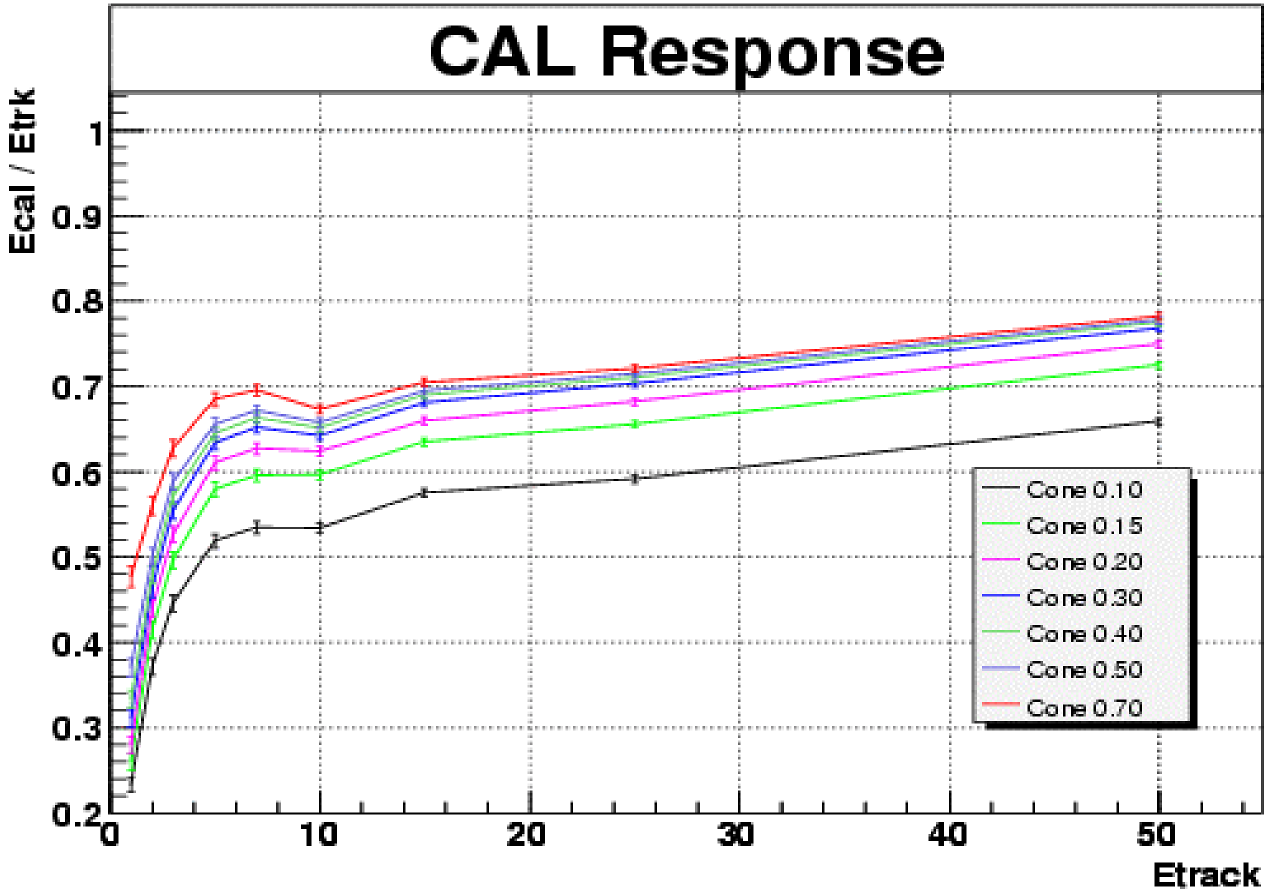
⟹ Need to obtain isolated pion sample with the final detector setup

Isolated pion studies: Goals and motivations

- Provide feedback to the development of the full GEANT based DØ detector simulation
  - Complex task: detailed material description, diversity of hadronic interactions, shorter integration time, etc.
  - E.g.: extrapolation of the Jet Energy Scale to kinematical regions which are not easily accessible with high statistics, like heavy quark jets or jets at highest energies
- Direct input and essential for the development of Eflow algorithms (to improve jet energy resolution)
  - Basic idea: Measure charged particles with the tracker and neutral ones with the CAL. Pion response needed to avoid double counting
- Tau energy resolution. Basic idea is the same as for Eflow, however simpler algorithm

- Disclaimer: the isolated pion study is work in progress

Single pion response in the MC

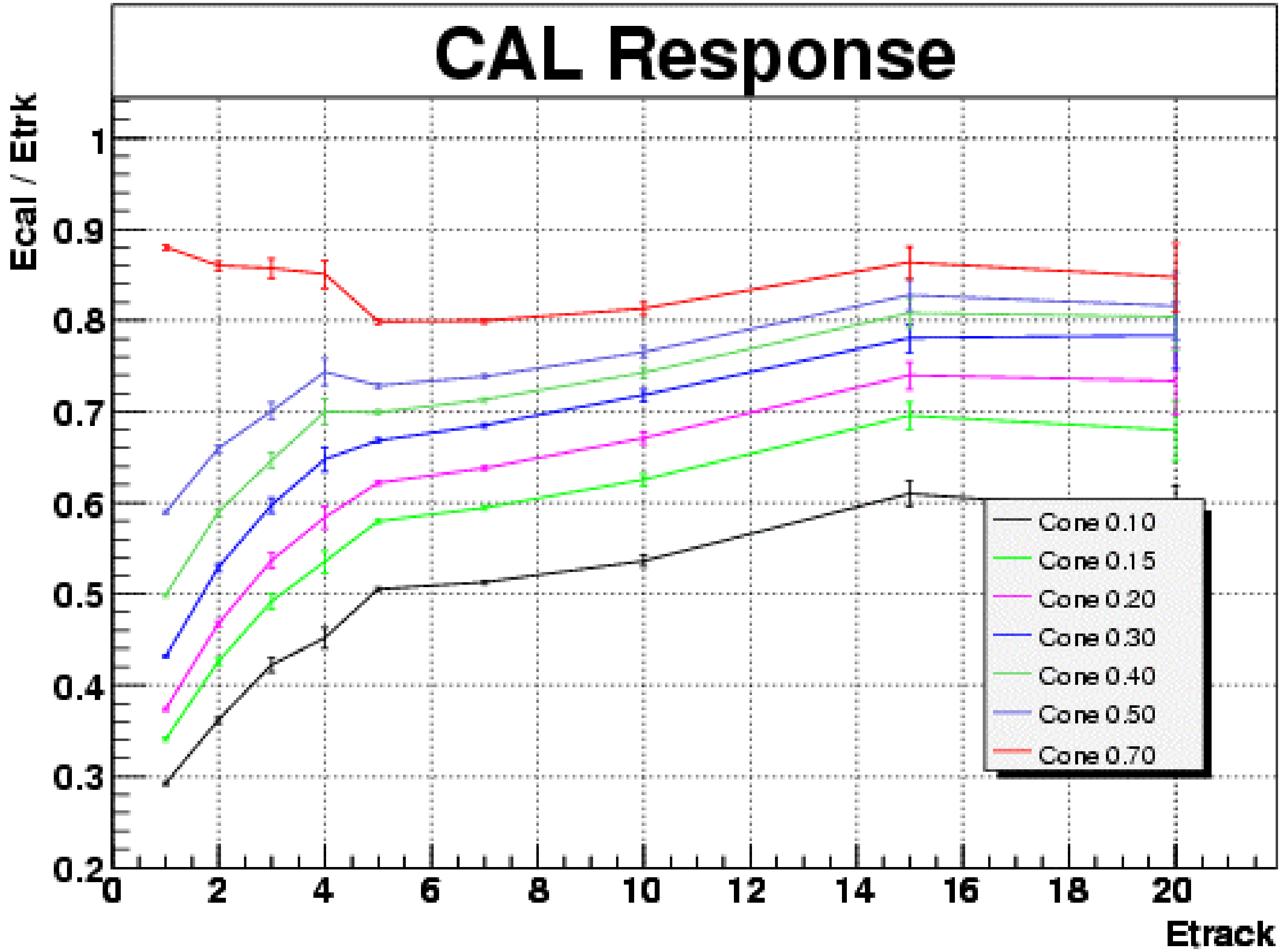


Understand pion showers and response (identify the effects that drive the overall shape and norm.)

Central region
$\eta < 0.5$

- Clear cones size dependence; above cone 0.5 mainly noise contrib.
- Shape of the response at low energies is strongly influenced by zero suppression, dead material, magnetic field, backscattering, etc.

Isolated pion response in data



Collected using a tracking based trigger with a threshold at $p_T > 5$ GeV

Central region $\eta < 0.4$

Data from a few days parallel to physics running

- Raw response as obtained from the data with an isolation cone 1.0. We still work on the background subtraction

Summary

- ϕ-intercalibration of the HCAL
  - The central CAL is now flat in ϕ at the order of 1% precision
  - Dominant effect for the spread of calibration constant is due to charge collection effects within the shorter Run II integration time.

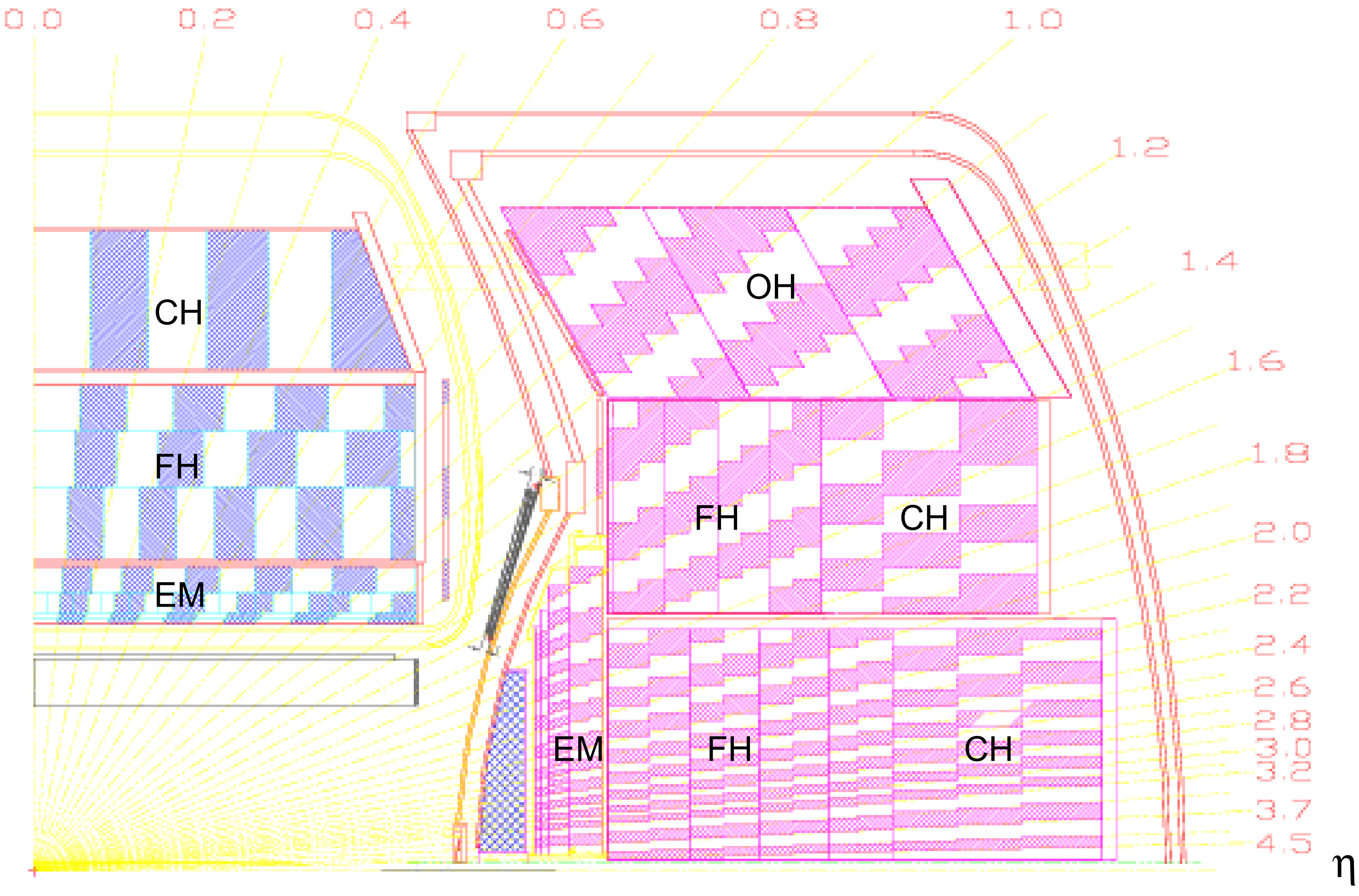
    The ϕ-intercalibration accounts for these
- η-intercalibration of the HCAL
  - Default constants optimize the jet energy resolution for ~45 GeV jets
  - The right scale is determined by the energy dependent Jet Energy Scale

➡ Significant improvement of the jet energy resolution due to the HCAL calibration

- Stability of the calibration will be monitored in the future
- Isolated pion studies
  - Isolated pion sample obtained with the final detector setup
  - CAL response and resolution to single hadrons is being determined *in situ*
  - Major effects that drive the response have been identified (although not discussed in detail in this talk)

Backup slides

DØ calorimeter



Isolated pion studies: Overview

Single pion MC

- Understand pion showers and response (identify effects that drive shape and overall norm.)
- Effect of dead material, magnetic field, noise, integration time, zero suppression, etc.

Monte Carlo

- Understand how to select isolated pions in data in an unbiased way
- Simulate trigger conditions
- Estimate backgrounds
  1. Energy contr. from neutral overlap
  2. Pions are mixed with (mainly) protons and kaons

Tune the MC

Data

- Min bias data (low energy pions)
- Dedicated triggers to reach higher energies (Tracking based triggers, with a threshold at pt > 5 GeV and 10 GeV)

Isolated pion studies: Overview

Single particle MC

- Compare data with a single particle MC which reflects the charged particle spectra depending on energy and η. In addition: take care of smearing effects due to binning in energy and η distribution
- Produce a single particle MC with the spectra of the isolated Min Bias MC

Monte Carlo

- Understand how to select isolated pions in data in an unbiased way
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