



Jet Reconstruction and Physics Performance with the 4th Concept

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Physics with jets

Most of the important Physics processes to be studied in the ILC experiment have multi-jets in the final state

Jet energy resolution is the key in the ILC Physics

The world-wide consensus of the performance goal for the jet energy resolution is

$$\sigma_E / E = 30\% / \sqrt{E(\text{GeV})}$$



Z/W → jj can be reconstructed and separated

Jet Reconstruction: my ingredients

for the studies
in the present talk

Physics events

- qq (q=uds) @ 91GeV
- WWvv @ 500 GeV
- ZZvv @ 500 GeV
- ZH(120)→vv cc @ 250 GeV
- ZZ→vv qq @ 250 GeV

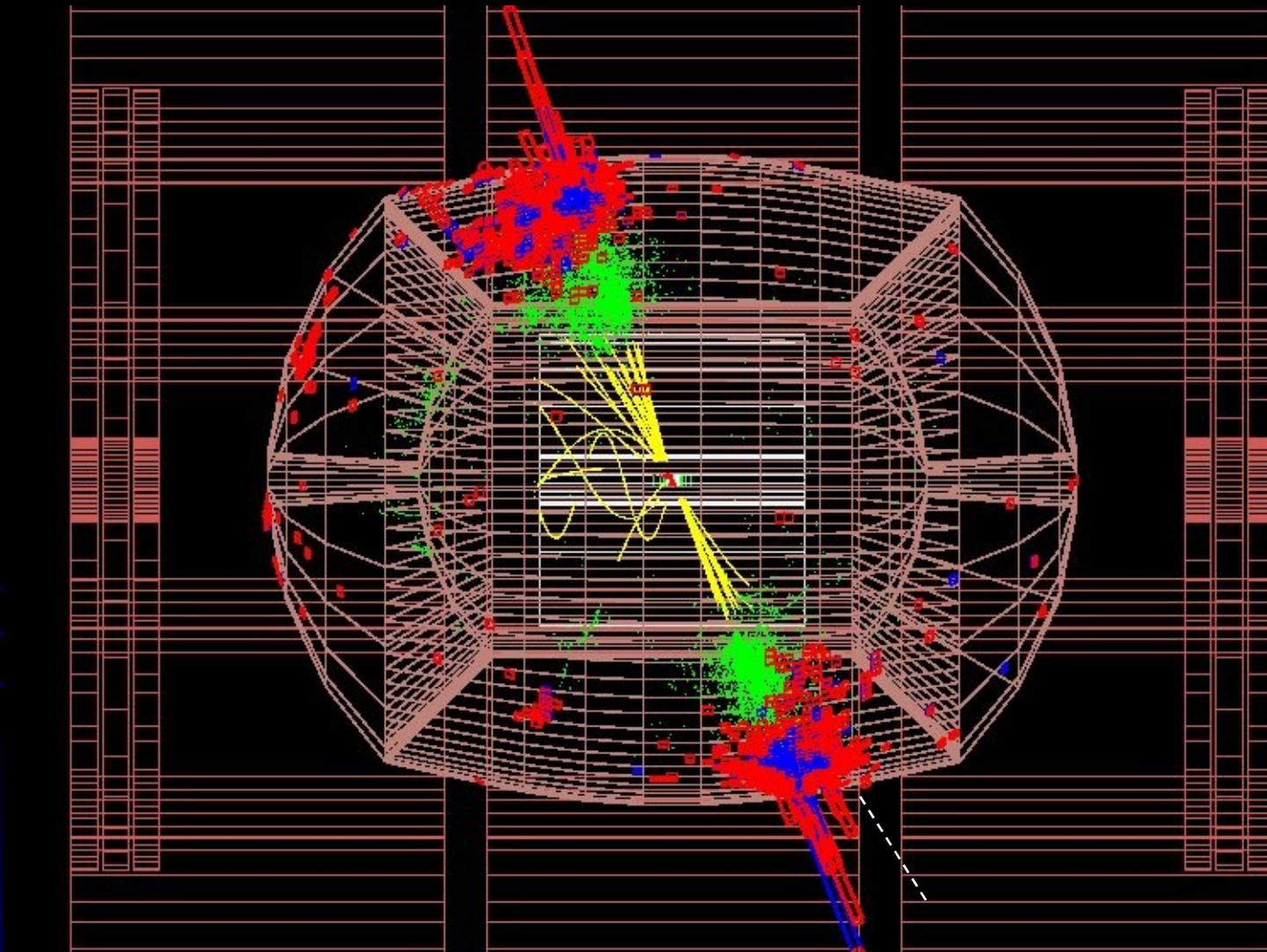
Detector & framework

- 4th Concept detector
- IlcRoot framework

Jet algorithm

- Existing algorithm (Durham)
- Combine informations from tracking and calorimetric objects
- Add reconstructed tracks in the muon spectrometer

500 GeV Di-Jet event display

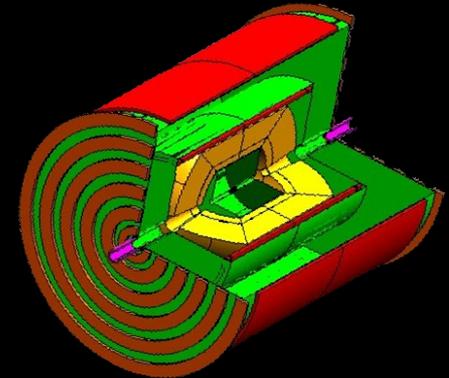


A Strategy for Jet Reconstruction

- Assume the jet made of 2 non-overlapping regions
 - Core: region of the calorimeter with overlapping showers
 - Outliers: hit cells separated from the core
- Measure the **Core energy**
using information from the calorimeter
- Measure the **Jet axis**
using information from the tracker detectors
- Reconstruct **Outliers** individually
using tracking and/or calorimetry
depending on the charge of the particle

4th Concept Detector

- VXD (SiD vertex)
- DCH (Clu Cou)
- ~~ECAL~~ (Cristal Dual Readout)
- HCAL (Fiber Dual Readout)
- MUDET (Dual Solenoid, Iron Free)



All the detectors present in these studies, except

Simulation Details

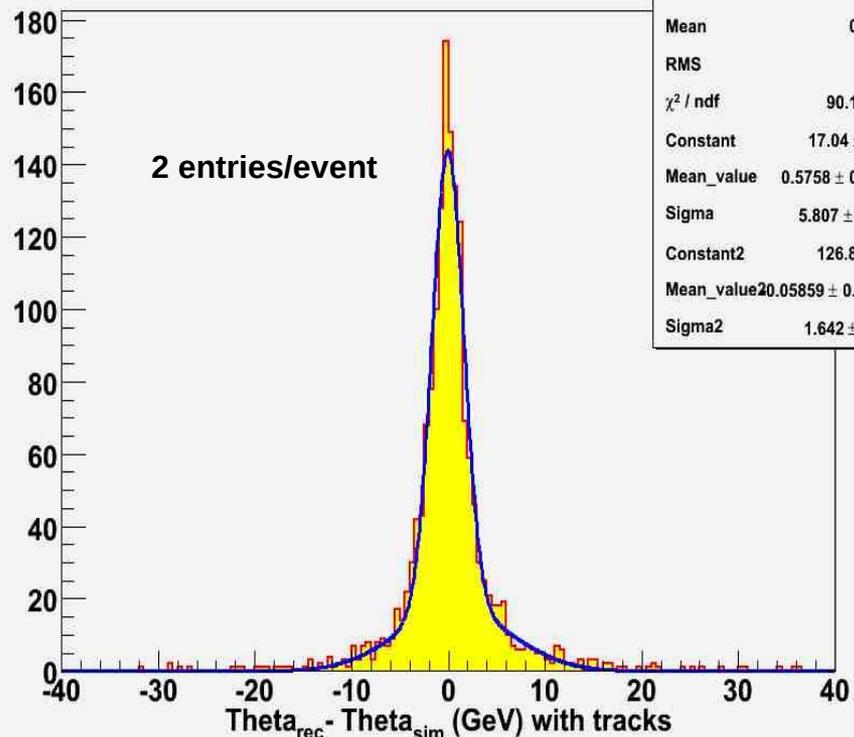
- **ILCroot** framework
- **Generated events:**
 - $e^+e^- \rightarrow Z \rightarrow qq$ ($q=uds$) @ 91 GeV (Pandora-Pythia) with ISR
 - $e^+e^- \rightarrow ZZ\nu\nu$ @ 500 GeV (Pythia 6.4)
 - $e^+e^- \rightarrow WW\nu\nu$ @ 500 GeV (Pythia 6.4)
 - $e^+e^- \rightarrow ZH \rightarrow \nu\nu cc$ @ 250 GeV
(KEK samples) with beamstrahlung
 - $e^+e^- \rightarrow ZZ \rightarrow \nu\nu qq$ @ 250 GeV
- **Fluka** to track particles in the detectors
- **Full Digitization/Clusterization** for VXD, DCH, and HCAL
- **Fast rec-points** (gaussian smearing of hits) for Muon detector
- **Full parallel Kalman Filter** for track reconstruction (see [F. Ignatov's talk](#))
- **Single tower** informations for the Calorimeter (see [V. Di Benedetto's talk](#))

Jet Reconstruction Performance at Z^0 -Pole (91 GeV) (di- jets events)

Study:

- Theta and Phi Resolutions
- Z^0 Mass Resolution

Jet theta resolution (Deg) with track objects



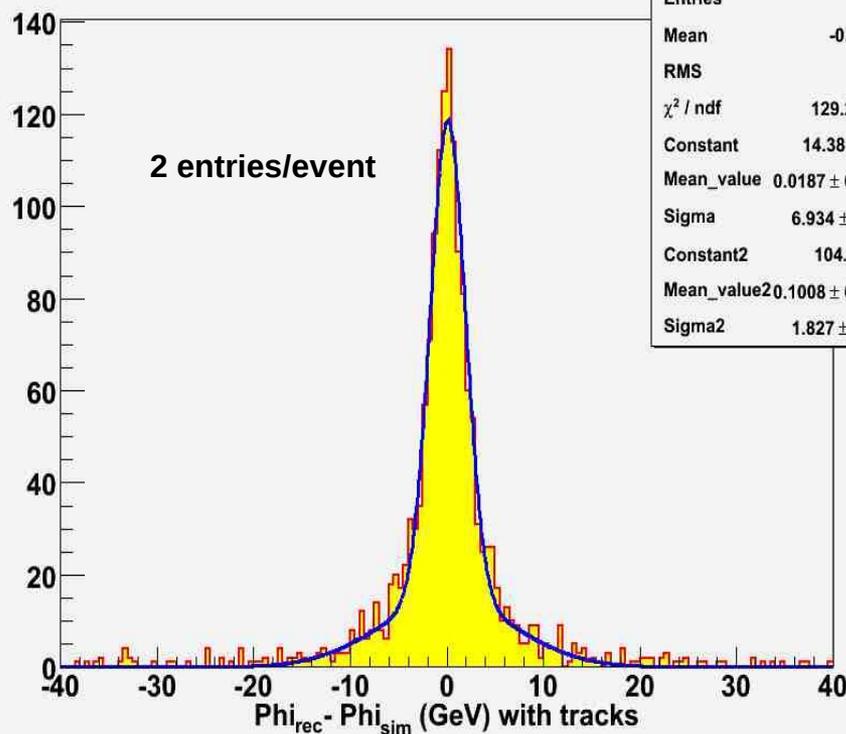
Find 2 jets from reconstructed tracks

$$(\theta_{\text{rec}} \quad \phi_{\text{rec}})$$

Find 2 jets from generated particles

$$(\theta_{\text{sim}} \quad \phi_{\text{sim}})$$

Jet phi resolution (Deg) with track objects



Jet axis resolution

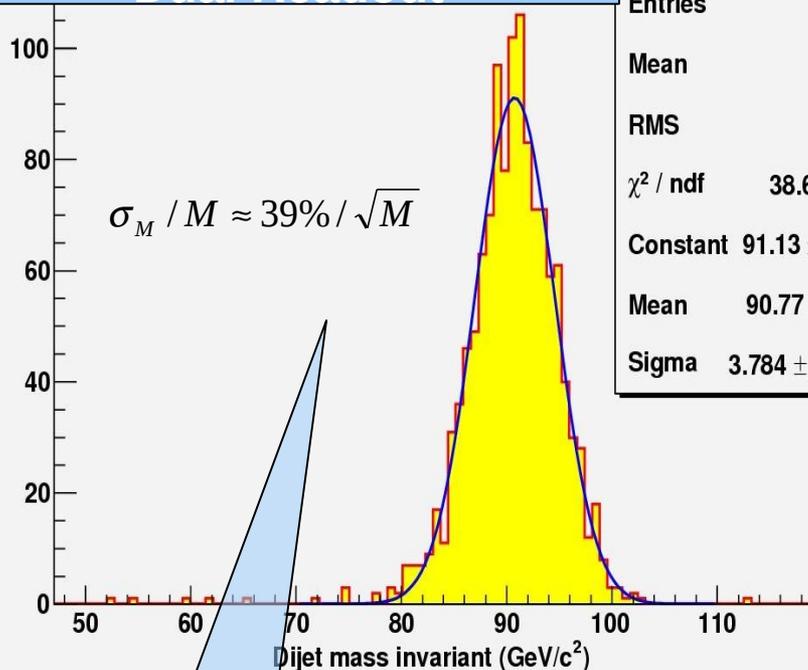
$$\sigma_{\theta} = 1.6^{\circ}$$

$$\sigma_{\phi} = 1.8^{\circ}$$

Dual Readout

htemp

Entries	1244
Mean	90.54
RMS	4.542
χ^2 / ndf	38.68 / 34
Constant	91.13 ± 3.33
Mean	90.77 ± 0.11
Sigma	3.784 ± 0.086



- Reconstructed 2 jets from track objects
- Reconstructed 2 jets from tower objects

$$E_{\text{tower}} > 100 \text{ MeV}$$

- no cut on theta

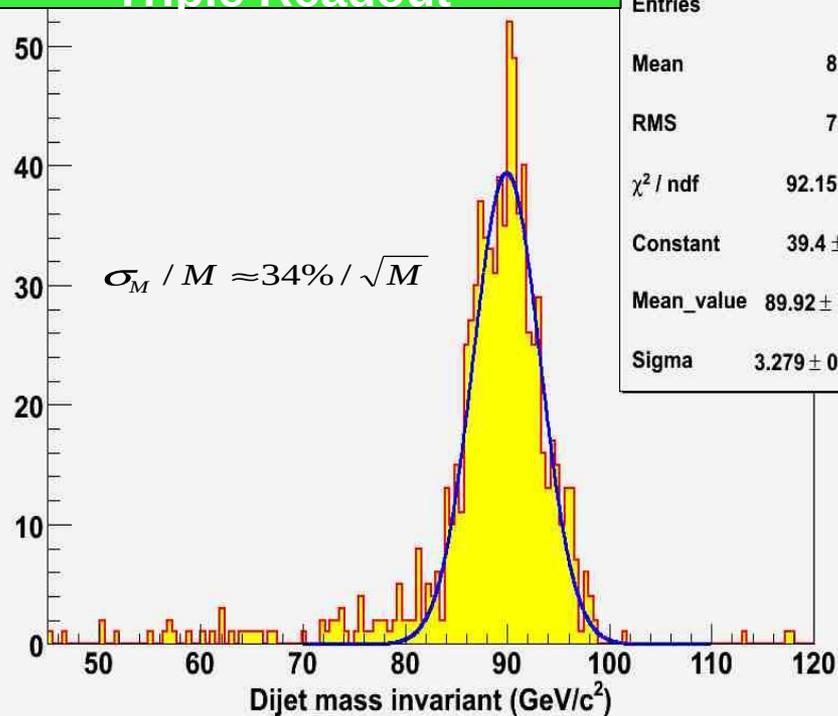
Presented at ALCPG07

Combine jet energy from calorimeter
and jet axis from trackers

Triple Readout

hZMass

Entries	828
Mean	88.47
RMS	7.072
χ^2 / ndf	92.15 / 56
Constant	39.4 ± 2.0
Mean_value	89.92 ± 0.14
Sigma	3.279 ± 0.098

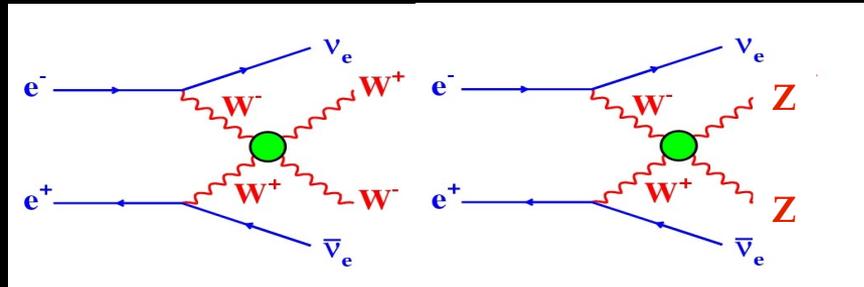


WW $\nu\nu$ and ZZ $\nu\nu$ @ 500 GeV

(4-jets events)

One of the goal of ILC is to distinguish WW from ZZ, using M_{jj}

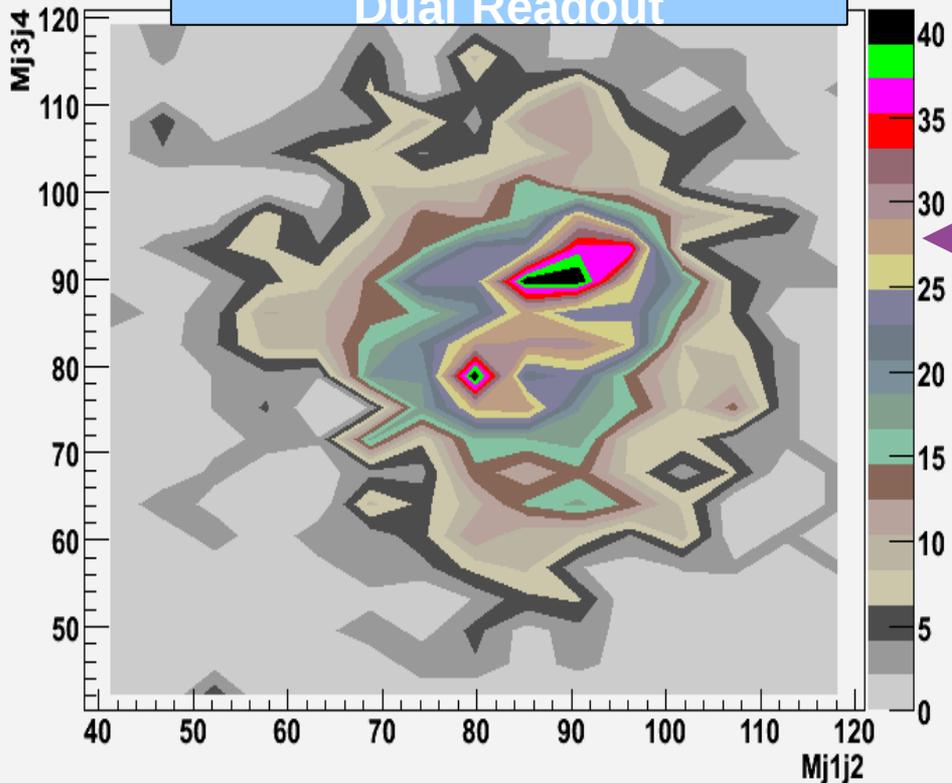
One of the benchmarks to evaluate calorimeter performance



- W/Z Mass Separation

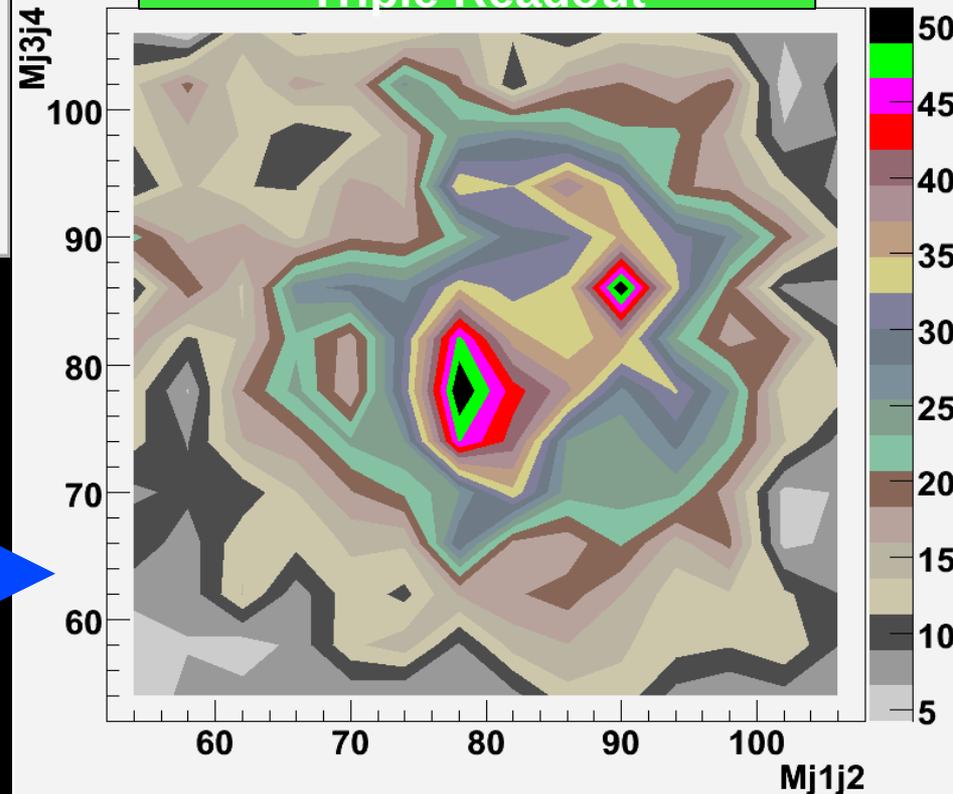
WWvv and ZZvv

Dual Readout

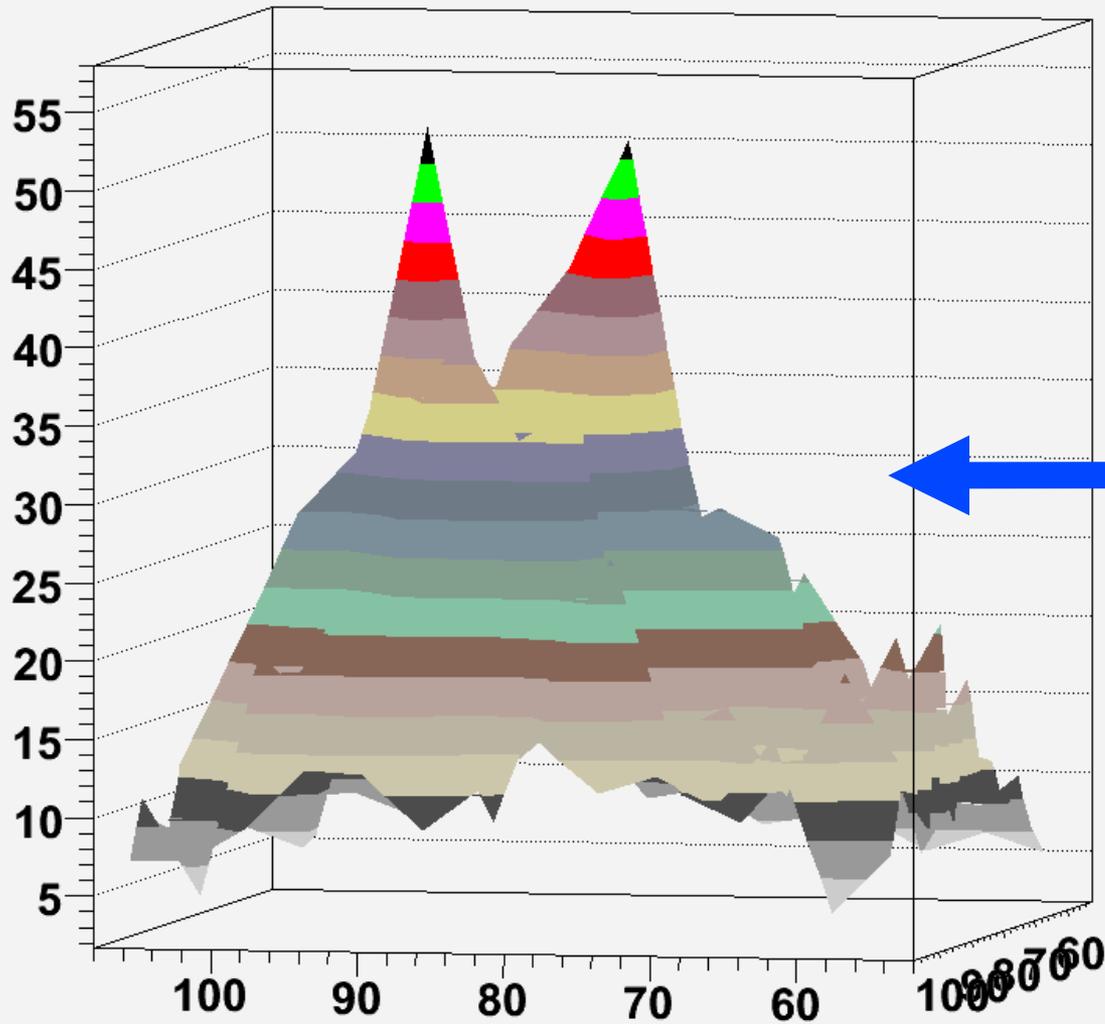


- Simple Durham jet-finder (fixed YCut) used for this analysis
- No combined information with tracking yet
- 4-jets finding efficiency: 95%
- Choose best pair combination

Triple Readout



- Combined informations with tracking
- 4-jets finding efficiency: 67.2%
- Choose best pair combination

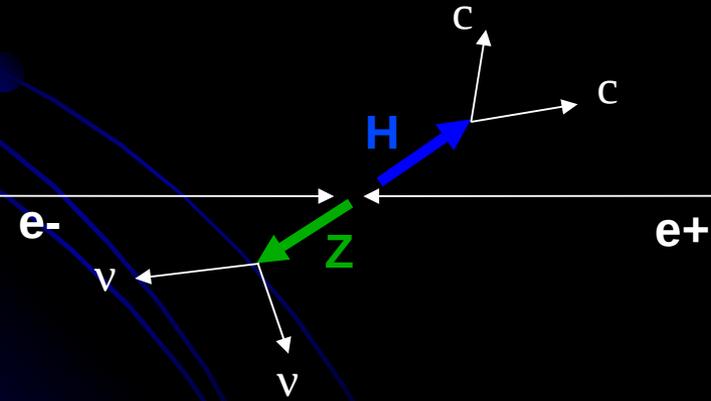
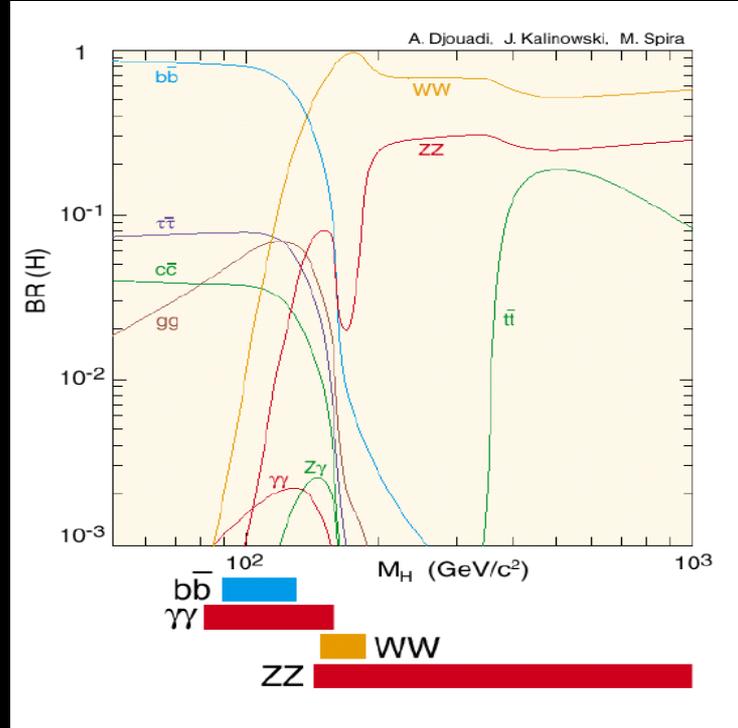


All combinations plotted

(6 entries/event)

ZH \rightarrow $\nu\nu cc$ Analysis

- For $M_H \leq 140$ GeV, large variety of channels decays for the Higgs: O(80%) bb, O(5%) cc
- One of the benchmark reaction for ILC
- To be tested:
 - Heavy flavour tagging, secondary vertex
 - Multi jet final state

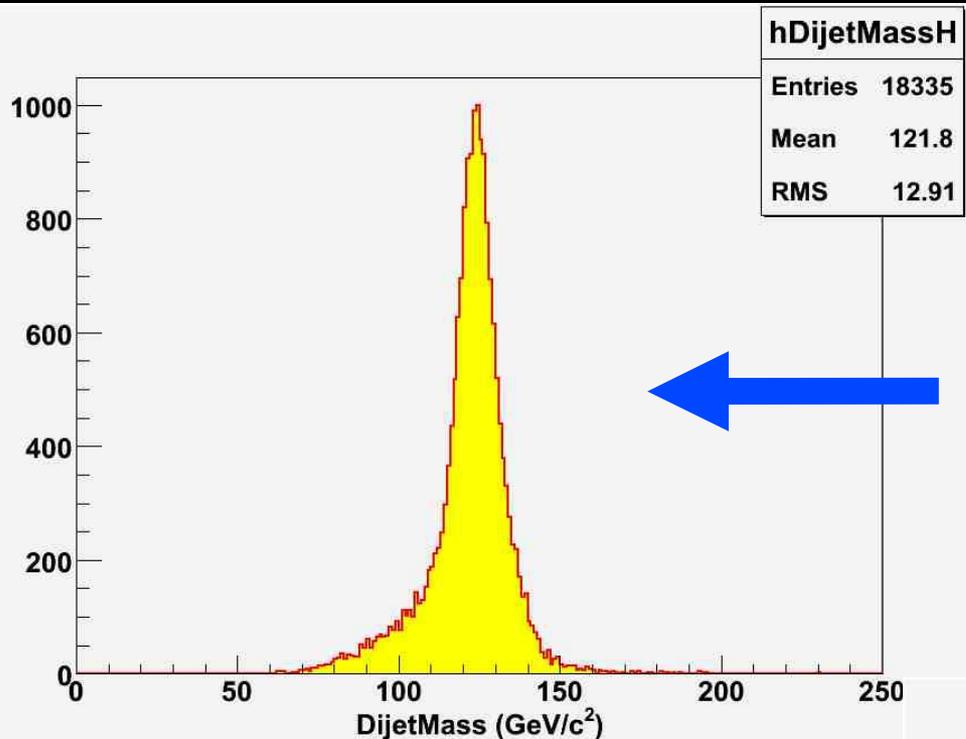


Current study

- KEK sample (signal):
<http://greentea.kek.jp/data/soft/samples/gen/jsf/250/zh2nnh250-bsA-100k.stdhep>
- Include only ZZ \rightarrow $\nu\nu\bar{\nu}\bar{\nu}$ background:
<http://greentea.kek.jp/data/soft/samples/gen/jsf/250/zz250-bsA-800k-nnqq.stdhep>
- Full sim/rec 22960 events for the signal
- Full sim/rec 15998 events for the background
- Event selection:
 - Look for 2 jets in the event
 - $E_{\text{vis}} > 130.0$ GeV
 - NO cut on the recoil mass
 - NO flavour tagging

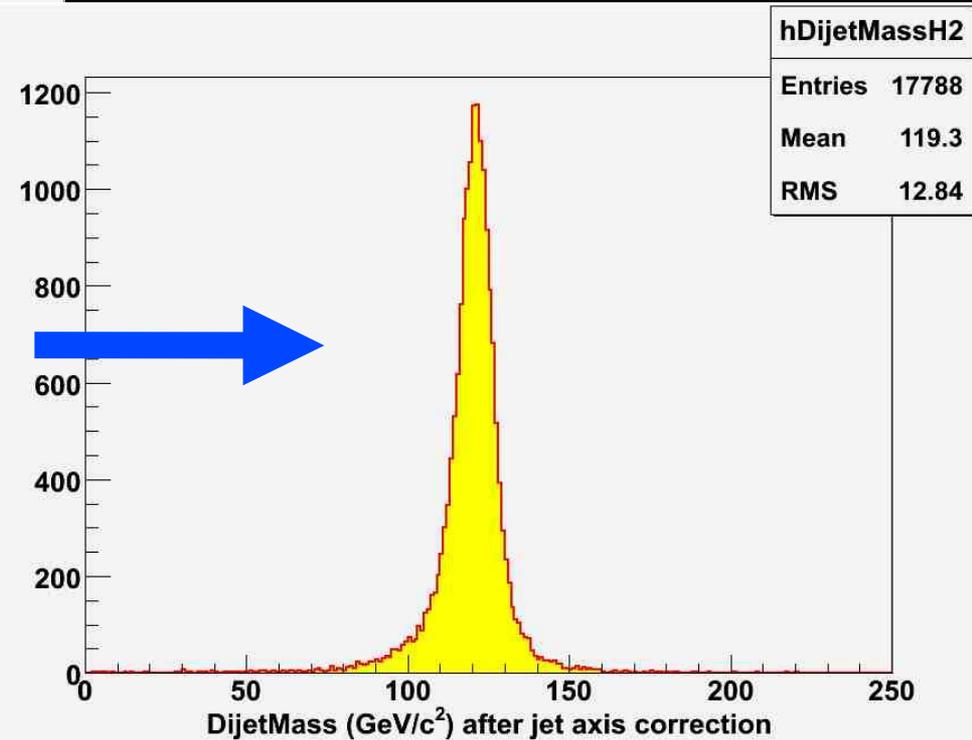
Very simple analysis
worst case scenario

ZH \rightarrow $\nu\nu CC$



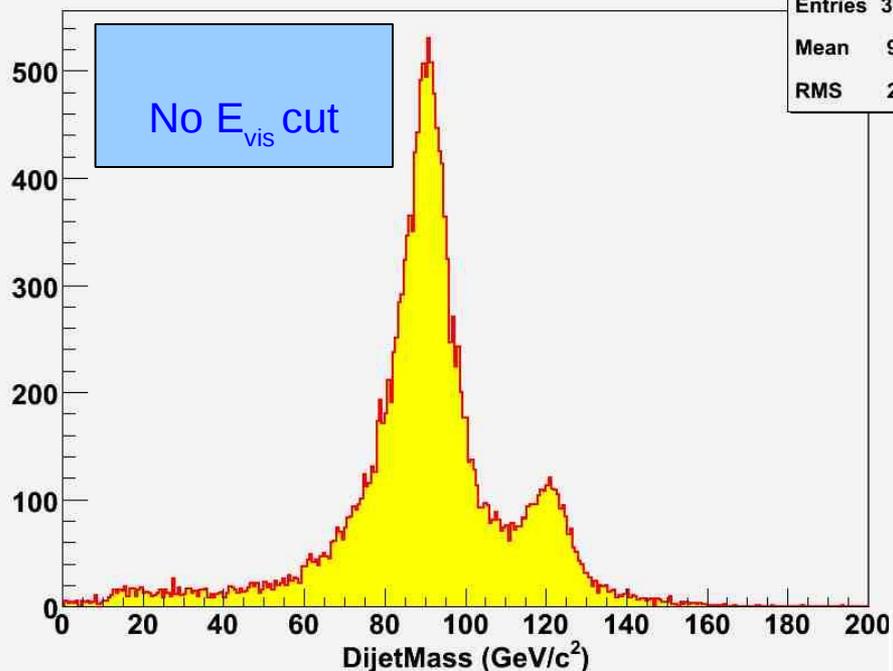
Results from jet finder with calorimeter only

After correction from tracker informations



ZH \rightarrow $\nu\nu$ CC

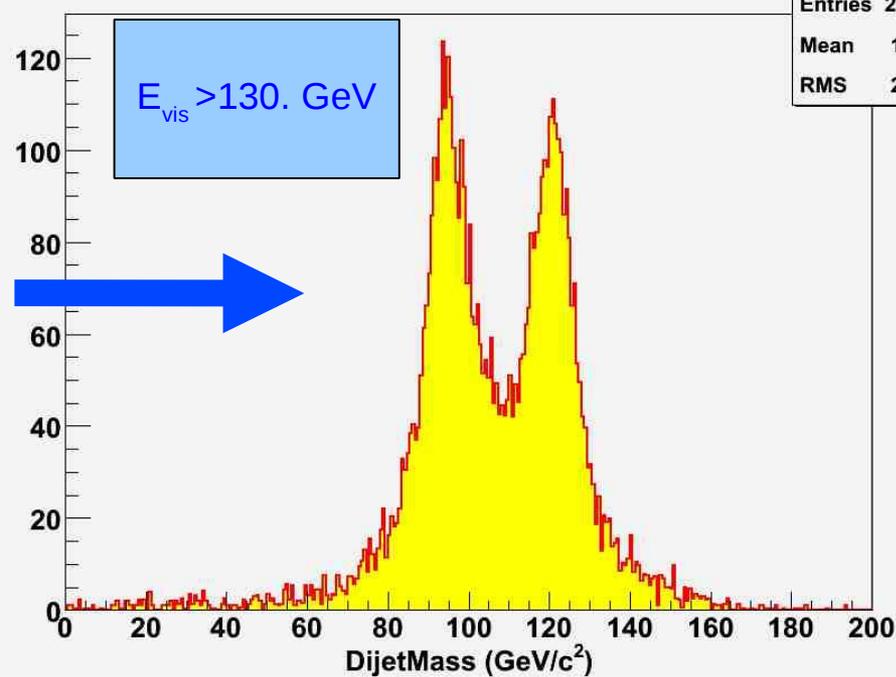
Signal + Background



hSigBkg

Entries	38178
Mean	90.45
RMS	21.68

Signal + Background



hSigBkg

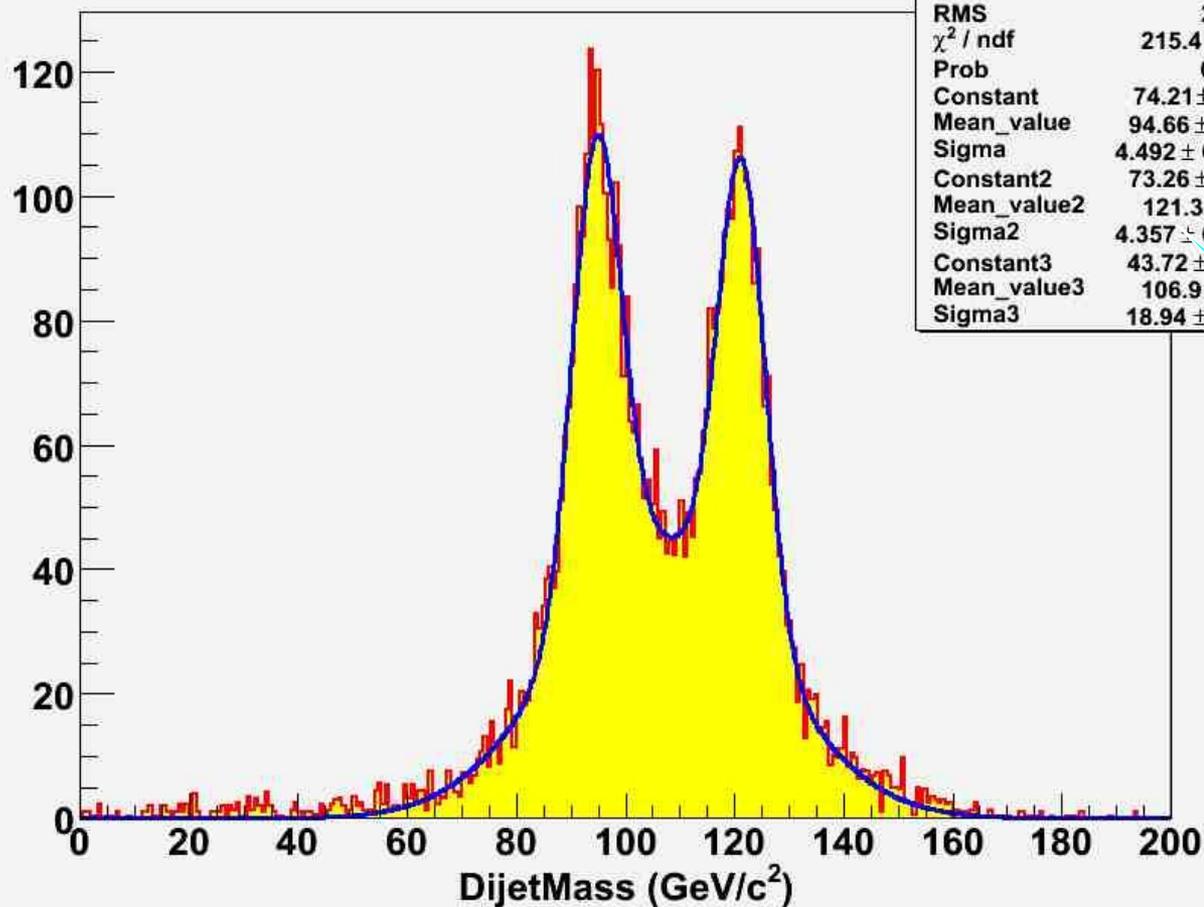
Entries	21566
Mean	106.3
RMS	20.06

Improving signal/background ratio

with E_{vis} cut

Signal + Background

ZH \rightarrow $\nu\nu$ CC



1% Error on the Higgs mass

- 2-jets finding efficiency: 96.6%
- E_{vis} cut efficiency: 82.2%
- Total selection efficiency: 77.4%

Summary

- Triple readout improves Physics performance compared to dual readout
- $\sigma/M \cong 34\%/\sqrt{M}$ Z^0 -Pole mass resolution
- W/Z mass well separated
- M_H precision ($ZH \rightarrow \nu\nu cc$) $\cong 1\%$
- **Still room for improvement**

Special thanks to the Lecce's group and Fedor Ignatov
who made these studies and results possible

Backup slides

4th Concept Software Strategy: ILCroot



Single Framework

- **CERN** architecture (based on *Alice's Aliroot*)
- Full support provided by Brun, Carminati, Ferrari, et al.
- Uses **ROOT** as infrastructure
 - All ROOT tools are available (I/O, graphics, PROOF, data structure, etc)
 - Extremely large community of users/developers
- TGenerator for events generation
- Virtual Geometry Modeler (VGM) for geometry
- Based on **Virtual Montecarlo**
- Could it ever evolve into a general purpose entity for the HEP community (as ROOT)?
- Growing number of experiments have adopted it: Alice, Opera, CMB, Panda, 4th Concept
- **Six MDC have proven robustness, reliability and portability**



Do not Reinvent the wheel
Concentrate on Detector studies and Physics

Requirements for ILC Detectors

- Good jet energy resolution to separate W and Z
- Efficient jet-flavor identification capability
- Excellent charged-particle momentum resolution
- Hermetic coverage to veto 2-photon background

Plans for Jet Studies

- **Use Compensating Calorimetry** for ILC and Durham jet finder algorithm
 - Study performance of the calorimeter and jet algorithm

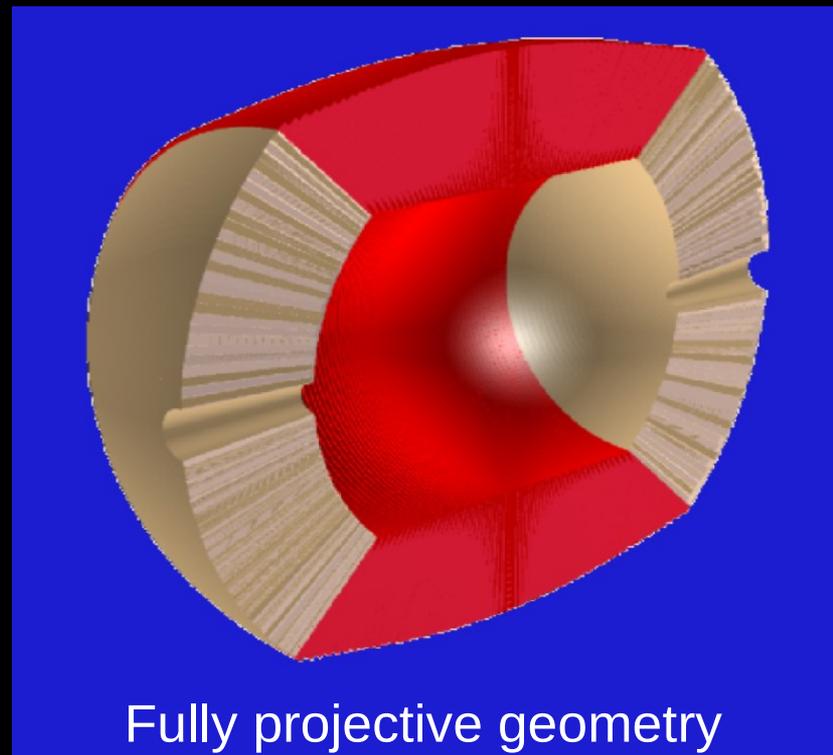
Present study

- **Improve Resolution** with proper treatment of “outliers”
 - Delicate interplay among tracking, calorimetry, and muon detector

In progress

Dual Readout Fiber Hadronic Calorimeter

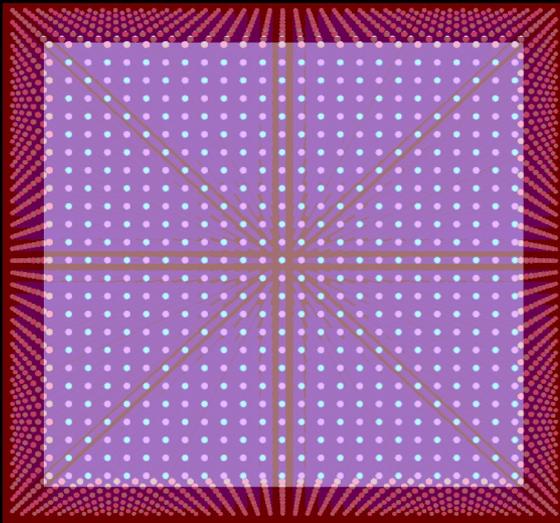
- Cu + scintillating fibers + Čerenkov fibers
- $\sim 1.4^\circ$ tower aperture angle
- $\sim 7.3 \lambda_{\text{int}}$ depth
- Azimuth coverage down to $\sim 2.8^\circ$
- Barrel: 16384 towers
- Endcaps: 7450 towers



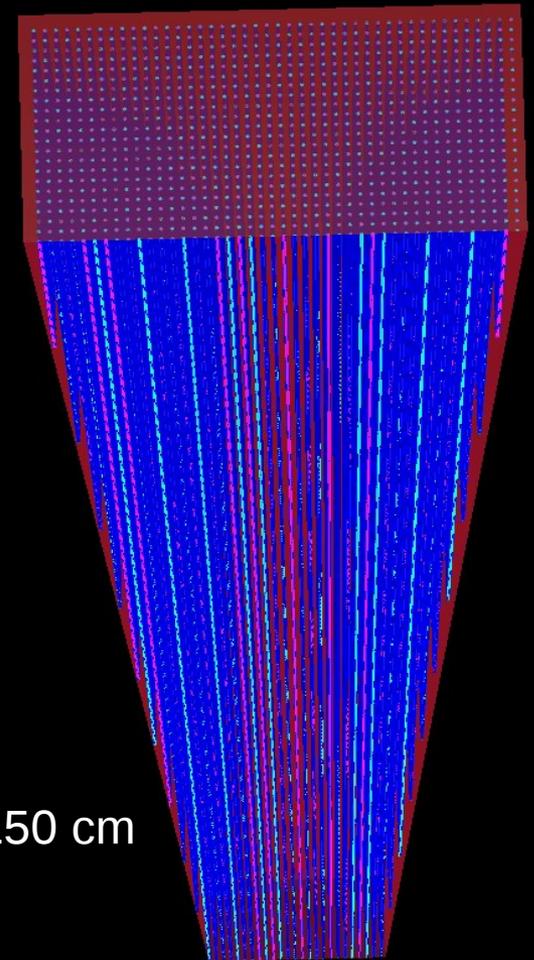
4th Concept Hadronic Calorimeter Towers

Top cell size: $\sim 8.1 \times 8.1 \text{ cm}^2$

Bottom view of single cell



Prospective
view of
clipped cell



Cell length: 150 cm

- Number of fibers inside each cell:
~1600 equally subdivided between
Scintillating and Cerenkov
- 500 μm radius plastic fibers
- Fiber stepping $\sim 2 \text{ mm}$

Bottom cell size: $\sim 4.4 \times 4.4 \text{ cm}^2$

Calibration

Energy of HCAL calibrated in 2 steps:

- Calibrate with single 45 GeV e^-
→ raw E_C and E_S
- Calibrate with single 45 GeV π^-
→ η_C , η_S and η_n