# Jet Calibration @ LEP2

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# Physics with hadronic jets at LEP2

Typical LEP2 analyses:

- **WW** physics (cross-section, BR's and **mass measurement**)
- **Higgs** search

(see previous talk)

CRUCIAL: good resolution of measured jet-jet invariant mass

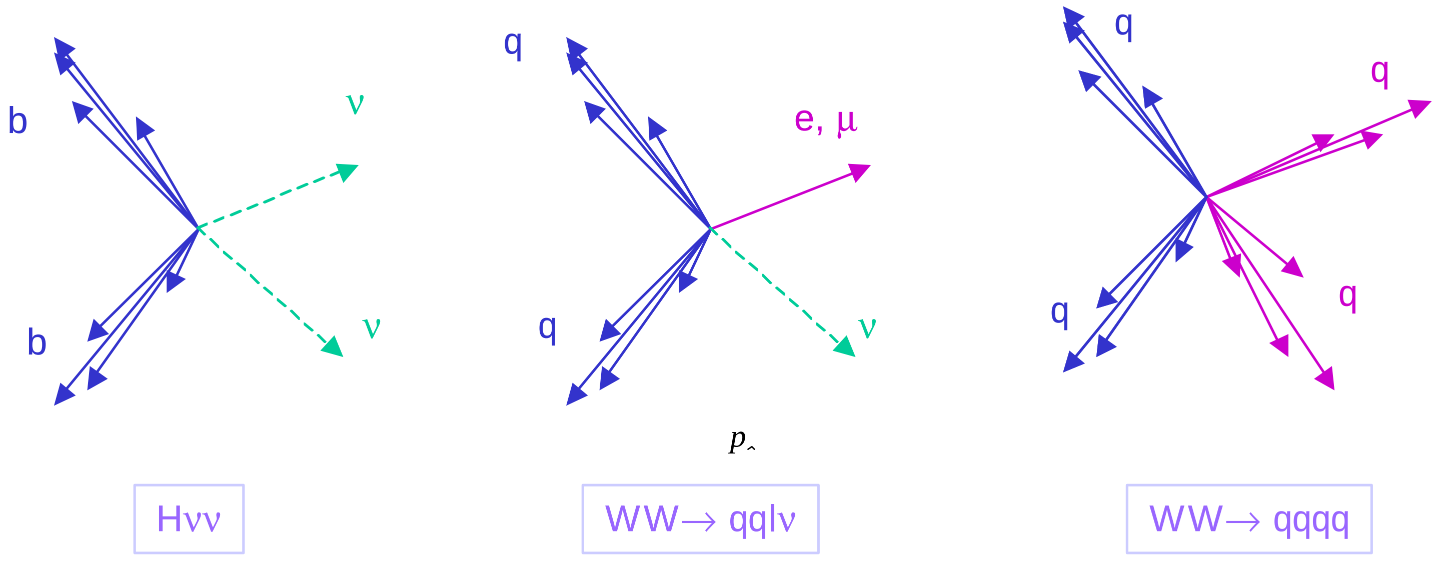
- Energy resolution
- angular resolution
- kinematic fit

CRUCIAL: good b-tagging performance

- angular resolution

# Hadronic jets

2-jet or 4-jet topology




Jet composition (at LEP1):

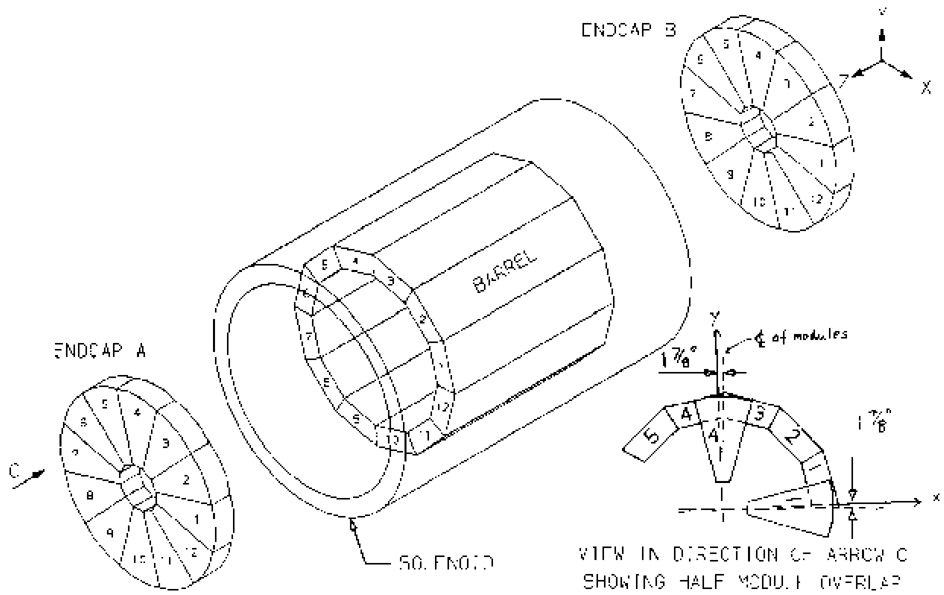
- ~60 % charged tracks
- ~40 % neutrals (photons+hadrons)
- neutrinos from b and c semileptonic decays

Tracking resolution (ALEPH): $s(p_\perp)/p_\perp = 0.0006\, p_\perp + 0.005$

# Calorimeters

ALEPH

## Electromagnetic Calorimeter (ECAL):



# Calorimeters

ALEPH

## Electromagnetic Calorimeter (ECAL):

lead + wire-chambers

angular granularity:
74,000 towers (0.9º x 0.9º)

energy resolution (electrons):

$$\frac{\sigma(E)}{E} = \frac{0.18}{\sqrt{E/GeV}} + 0.009$$

### calibration

Online gain monitoring:

(constant pressure)

$^{55}$Fe source

2%-3%
↓
0.3%

Offline calibration:

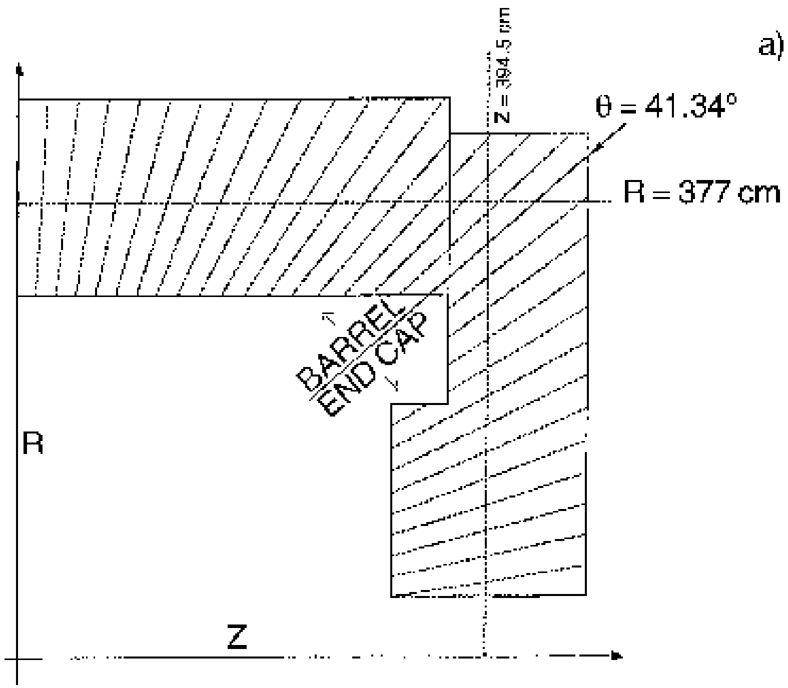
•electrons from: .., . . e.. ,
Bhabhas at Z peak and
at high energies
•compare to track momentum

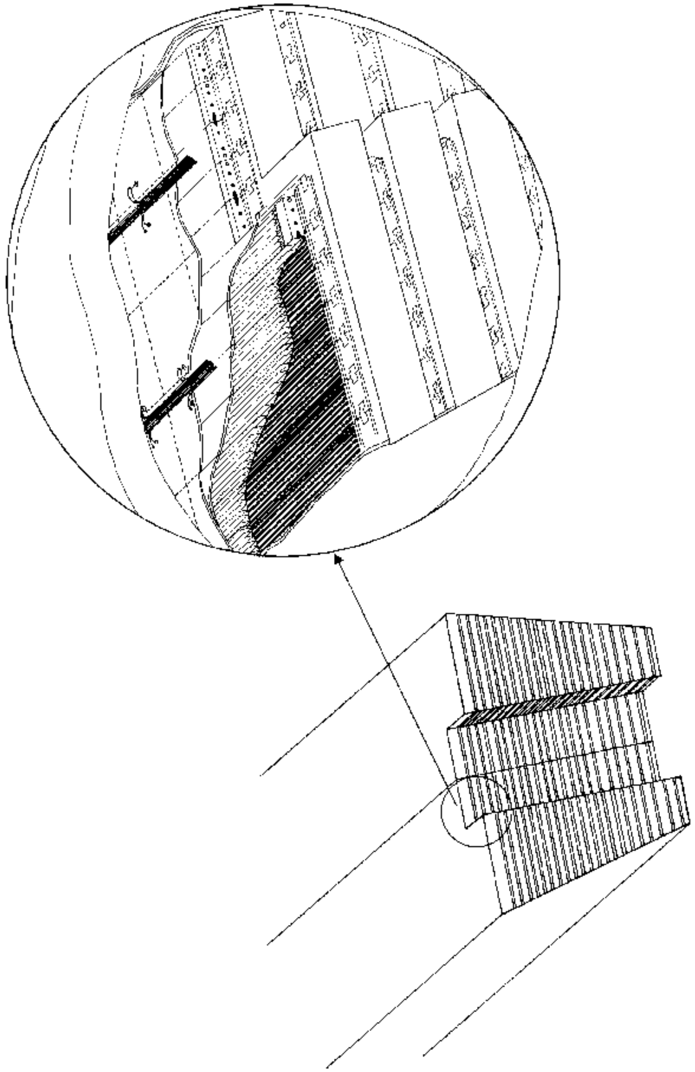
Total uncertainty: ~0.7%

# Calorimeters

ALEPH

## Hadron Calorimeter (HCAL):



# Calorimeters

ALEPH

## Hadron Calorimeter (HCAL):

iron + streamer tubes

angular granularity:
4788 towers (3.7º x 3.7º)

energy resolution
(pions at normal incidence):

$$\frac{\sigma(E)}{E} = \frac{0.85}{\sqrt{E/GeV}}$$

### calibration

Online gain monitoring:

(p,T variations)

monitoring tubes 10% $\downarrow$ 0.4%

Offline calibration:

- muon peak . reference value (beam test)
- use .. . .. to monitor time dependence (@ LEP2)
- Z peak data for module-to-module variations

Total uncertainty: ~2%

# Energy flow

Needed to improve the resolution on jet energy and direction

( @LEP1: Higgs search, Heavy Flavour physics)

HF tagging based on
- lepton p_t
- impact parameter

need good resolution on jet direction

ALEPH

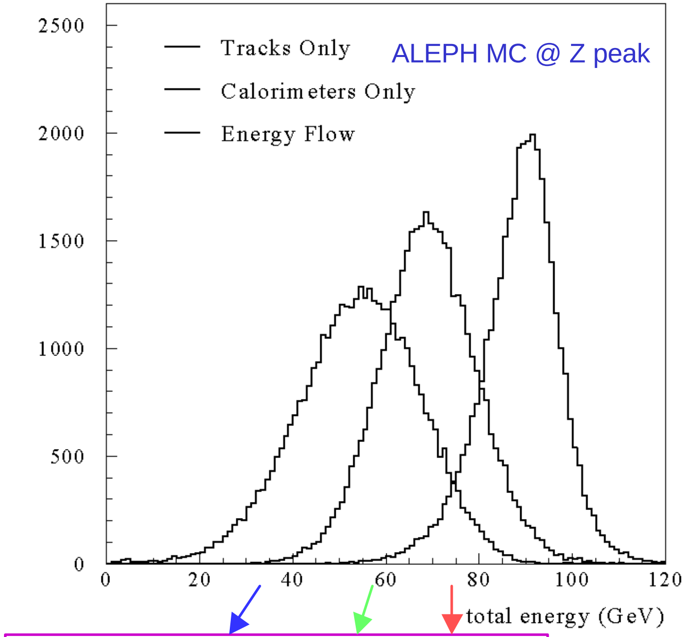
- Keep only 'good' charged tracks
- Recover tracks from $V^0$'s pointing to vertex
- 'Clean up' the calorimeters (noisy channels)

- Use particle ID (photons, muons, electrons)

- 'e.m. neutral' objects = photons,
  excess ECAL energy
  linked to electrons

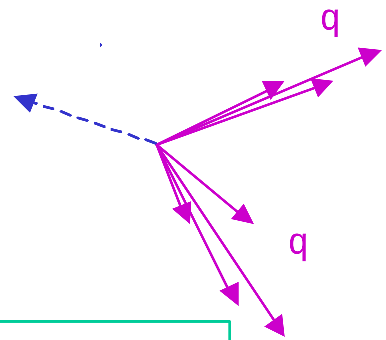
- 'hadronic neutrals' = isolated clusters
  'excess' energy for
  clusters linked to tracks

weights for the 4 energy contributions (3 ECAL stacks + HCAL) taken from beam test

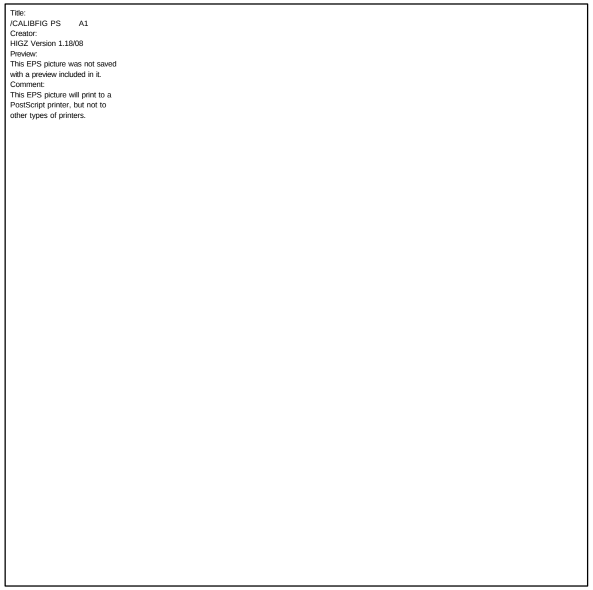



| | | | |
|---|---|---|---|
| $\sigma(E)/E$ = | 0.22 | 0.13 | 0.07 |
| $\sigma(\theta)$ = | 1.6º | 1.4º | 0.9º |

# Energy Flow: control analysis (LEP1)




$Z \to q\bar{q}$ events




compute $m_{had}$ from

- Jet-jet invariant mass
- Recoiling mass from p, E

$$\sigma(E) = [(0.59 \pm 0.03)\sqrt{E/GeV} + (0.6 \pm 0.3)]GeV$$

# Jet-Jet mass measurement

W mass

Higgs search

$$M_{ij}^2 \quad 2E_iE_j(1-\cos\theta_{ij})$$

→ energies

→ angles

E~50 GeV

. (E)/E ~ 10% → . (M)/M ~ 14%

(just from jet energies)

Kinematic rescaling → E,**p** conservation: freeze jet angles, rescale energies

HZ . qqbb (ALEPH)

Kinematic fitting →

- 4C E,**p** conservation
- 5C E,**p** conservation + 1 mass constraint
- 2C 5c + missing momentum

→ $M_{w1}=M_{w2}$

→ $M_{qq}= M_Z$ in HZ . qqbb

Jet (lepton) energies and angles

→ corrected for expected bias

→ varied within expected resolution

From Monte Carlo !!

Reconstructed mass resolution improved by a factor of 3

Physics measurement → (e.g. C.L. determination for Higgs search)

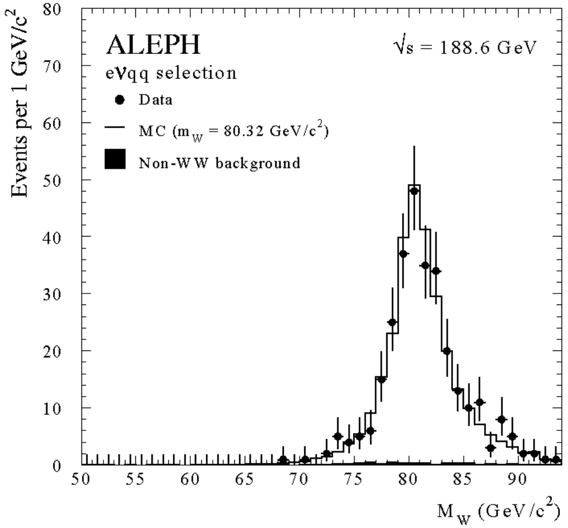
Determination of $M_W$

Depend totally on MC

DELPHI: 'ideogram' (likelihood)

ALEPH, OPAL, L3: MC reweighting

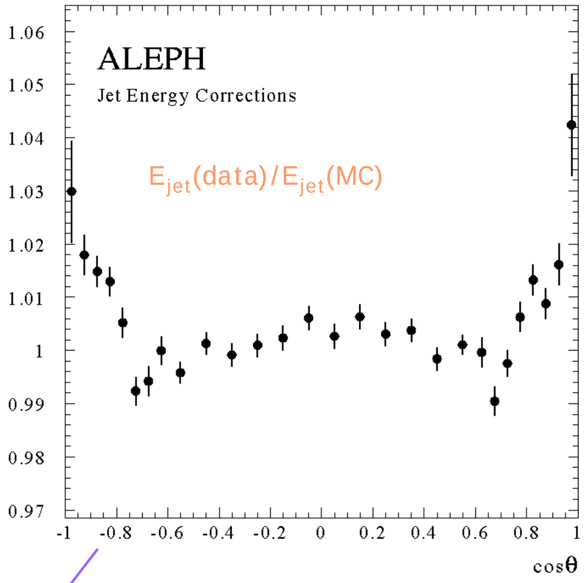
Vary input $M_W$ in MC
until
reconstructed $M_W$ distribution fits data




Data/MC discrepancies → corrections ⇕ systematics

# Data/MC comparison: use of 'calibration' Z peak data

Compare data/MC **jet energies** vs. polar angle




within 1% except in forward region

(b-tagged jets for Higgs search)

ALEPH, OPAL, DELPHI: correct MC jets

(assume corrections independent of E)

statistical uncertainty = systematic error

OPAL, DELPHI: check energy-independence using $Z \to q\bar{q}g$ (3 jets)

Jet energy resolutions also compared

ALEPH: compatible with jet energy ratio:
residual discrepancy (10% forward region) $\to$ systematic error

(other experiments: similar)

Computed year-by-year: take into account detector effects such as calibration variation

# A different approach: 'Upstream' corrections

Jet corrections → applied at the end of reconstruction stream → Take into account data/MC differences from any source

ALEPH

Getting closer to discrepancy source:

Rescale calorimeter energy in MC

- as a function of polar angle (from data/MC comparison @ Z peak) ( < 8% )
- as global random fluctuation (to simulate calibration fluctuations *vs.* time) ( < 1% )

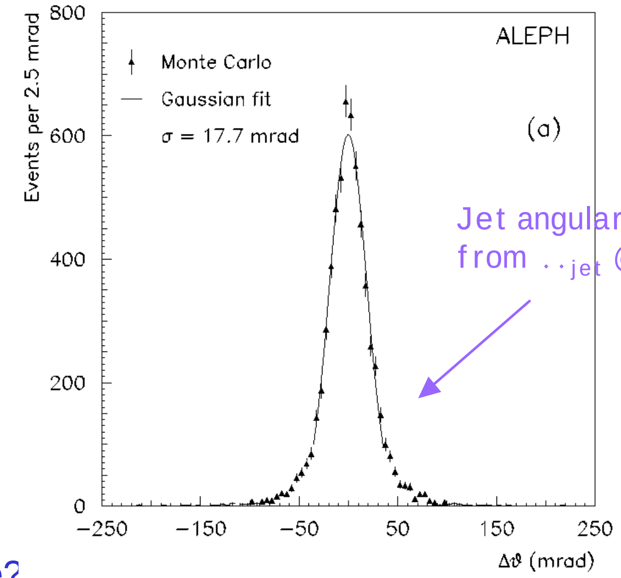
and vary 'downstream' jet corrections accordingly !!!

Deviation from central value taken as systematic error

# Jet angles:

Measured much better than energies

E(jet) ~ 45 GeV ⇒ $\sigma(p_\parallel)/p \;\; 10\%$ ; $\sigma(p_\perp)/p \;\; 2\%$ (ALEPH)




Jet angular resolution from $\Delta\theta_{jet}$ @ Z peak

Bias in angular reconstruction: any data - MC difference?

Not trivial: Z peak jets are back-to-back ⟶ biases cancel out

maximum observed discrepancies (ALEPH)

- angular resolution: use $\sigma(\theta_1-\theta_2) = \sqrt{2}\,\sigma(\theta)$ to compare data-MC — ~3.5 mrad
- angular bias: compare directions of jet components from different detectors (*e.g.* tracks *vs.* photons) — ~2 mrad (forward region)

correction/smearing

⇓

systematic error

## Summary of Systematic Uncertainties on $M_W$ from Detector Effects

(e+ .)

| ALEPH | . M l .qq (MeV) | . M qqqq (MeV) |
|---|---|---|
| •Tracking | 8 | 3 |
| •lepton angle bias/resolution | 15 | - |
| •lepton energy resolution | 8 | - |
| •Jet energy corrections (stat. err.) | 6 | 5 |
| •Jet energy resolution | 10 | 7 |
| •Calorimeter simulation | 13 | 10 |
| •Jet angles | 4 | 5 |

# Conclusions

- Calorimeters do play an important role in physics with jets at LEP2

  Angular granularity + particle ID capabilities

  ⇩

  Good performance of E-flow algorithms

- Good detector simulation really important if we want to reduce systematics