W Mass and Width at LEP2

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On behalf of the LEP collaborations

31st INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS AMSTERDAM

Overview

- Introduction
- W mass and width from direct reconstruction
  - Event selection
  - Invariant mass reconstruction
  - Mass and width extraction
  - Systematic uncertainties
- Results
- Summary and outlook

Introduction

- W Mass central component of Standard Model
- M_W predicted indirectly using G_F, α and M_Z from LEP1:

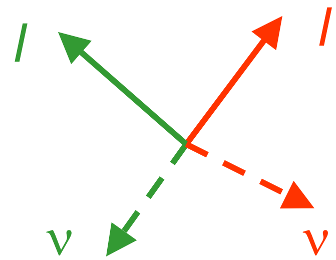
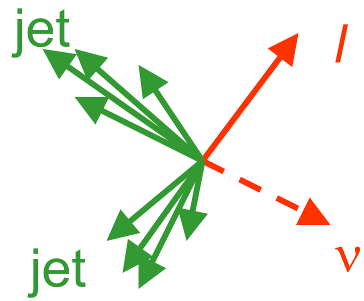
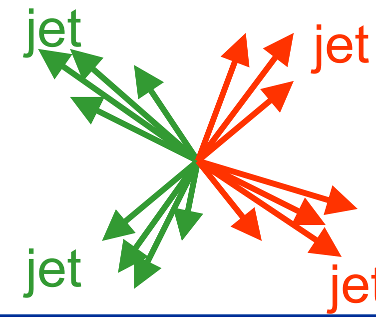
$$M_W^2\left(1-\frac{M_W^2}{M_Z^2}\right)=\frac{\pi\alpha}{G_F\sqrt{2}}\left(1-\Delta r\right)$$

Contributions from M_H and m_t

- Direct measurement of M_W provides
  - Test of Standard Model
  - Constraint on Higgs mass

- LEP2 provides clean environment
- Total of ~2500 pb^{-1} data yields ~40,000 WW events

Event Selections

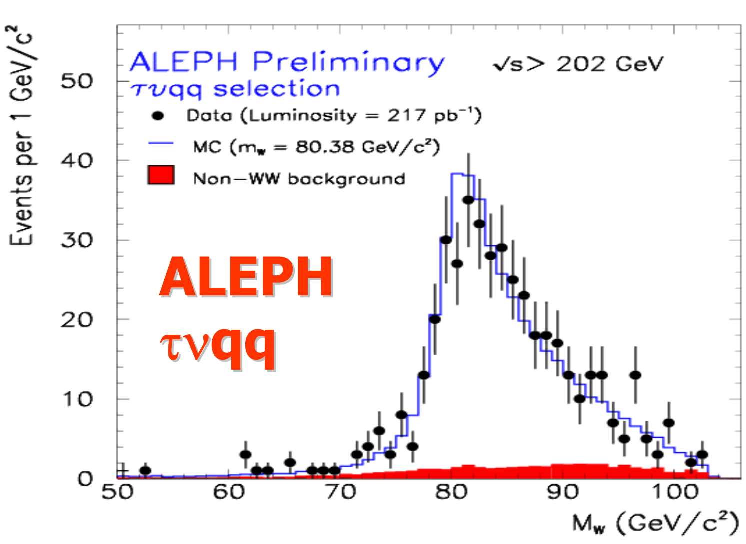
Channel			
Branching ratio	~10%	~44%	~46%
Typical Signature	Two energetic, acoplanar leptons Large missing energy and momentum	Two hadronic jets, one energetic isolated lepton, missing energy and momentum	Four hadronic jets, little missing energy and momentum
Main Backgrounds	ZZ,Zee,$\gamma\gamma$	Weν, qq(γ)	qq(γ)
Efficiency	~50%	~70%	~85%
Purity	~90%	~95%	~80%

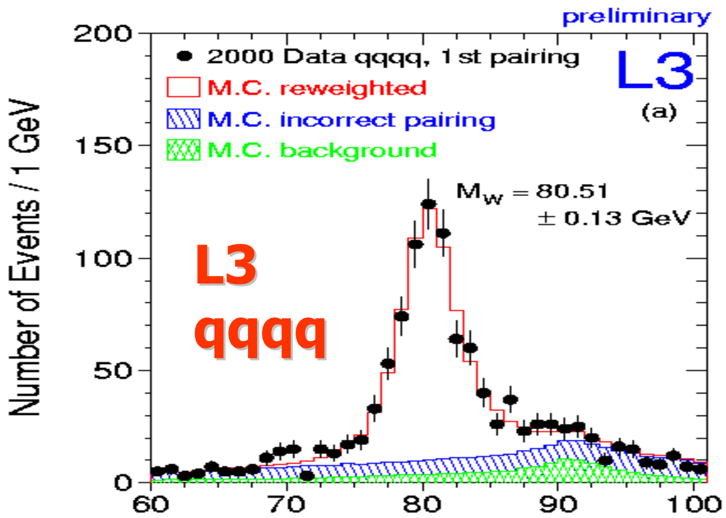
Invariant Mass Reconstruction

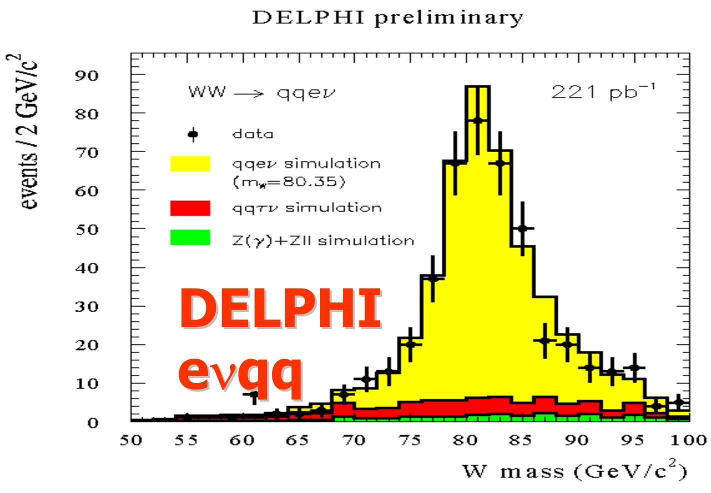
- Cluster jets and reconstruct lepton
- Apply kinematic fit
  - Use precise knowledge of E_{CM} to constrain energy and momentum of event
  - Improves resolution
  - Optional equal mass constraint
- In the fully hadronic channel need to pair jets (three-fold ambiguity)
- Form Invariant Mass:

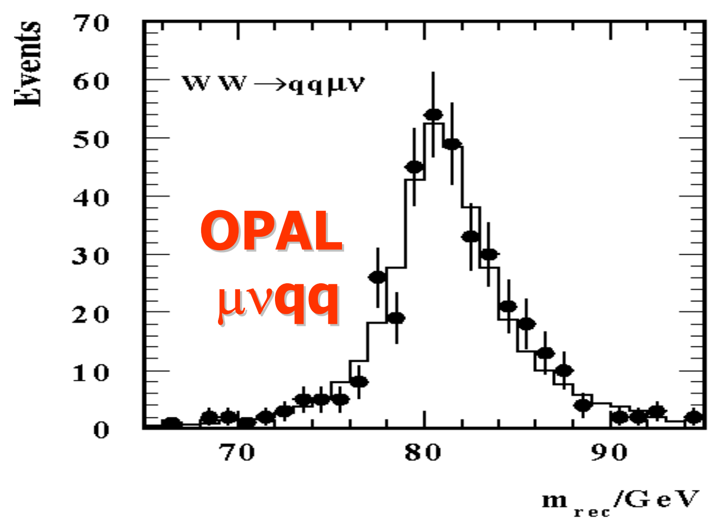
$$M_W^2 = \left(\sum_{i=1}^{n} E_i \right)^2 - \left(\sum_{i=1}^{n} \mathbf{p}_i \right)^2$$

Reconstructed M_W







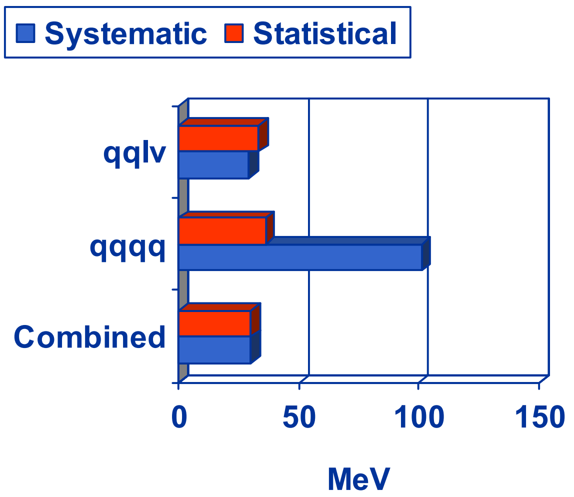


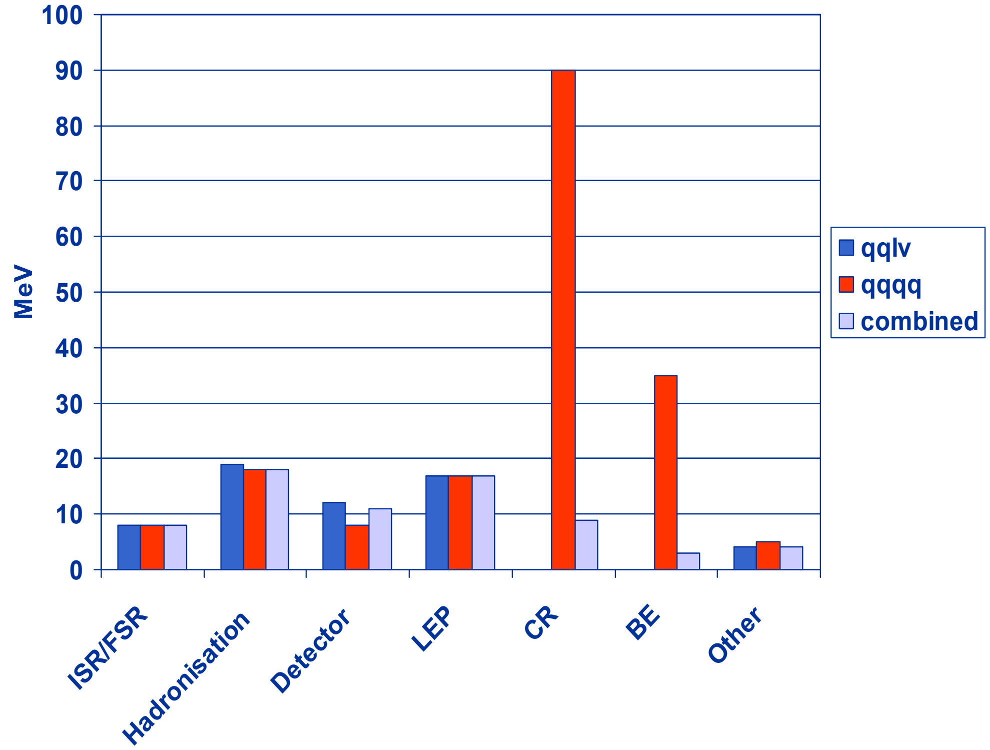
W Mass and Width Extraction

- Two main methods
  - Monte Carlo reweighting
    - Weight Monte Carlo (with known M_W) to fit data.
    - Data and MC treated identically, no bias correction needed
  - Convolution technique
    - Fit reconstructed mass distribution with function convoluting Breit-Wigner function and detector resolution
    - Correct bias by calibrating using Monte Carlo
- SM model relationship between M_W and Γ_W assumed
- Width obtained in 2 parameter fit
  - No relationship between M_W and Γ_W assumed

Systematic Uncertainties

- W mass measurement now dominated by systematic uncertainties:





Total syst 30 MeV

Total stat 30 MeV

Weight of qqqq channel 9%!

In absence of systematics, statistical error = 22 MeV!

LEP Beam Energy

- LEP centre of mass energy used in kinematic fit, translates directly to error on M_W:

$$\frac{\Delta M_W}{M_W} = \frac{\Delta E_{beam}}{E_{beam}}$$

- Fully correlated between channels and experiments
- E_{beam} obtained from measurements of total bending field
- Calibrated using resonant depolarisation
  - Only works up to 60 GeV, extrapolated to LEP 2 energies
  - Extrapolation gives main uncertainty on beam energy:

$$\Delta E_{beam} \approx 21\,\text{MeV}, \quad \Rightarrow \quad \Delta M_W \approx 17\,\text{MeV}$$

- Cross checks ongoing
- Expect final paper and value of uncertainty later this year

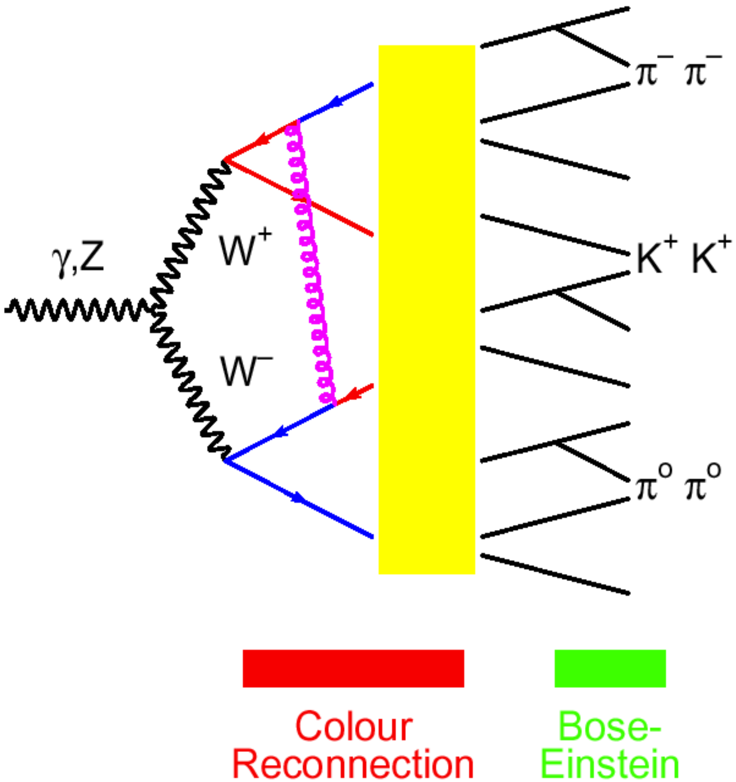
Fragmentation / Hadronisation

- Largest uncertainty from analysis
  - Assumed correlated both between channels and experiments
  - Important for both qqqq and lvqq channels
- Limitations of Monte Carlo to simulate particle content of jets (e.g. Baryon rates), and particle spectra.
- Interplay with detector simulation
- Compare different MC models (JETSET, ARIADNE, HERWIG) – take largest difference as error

$\Rightarrow$ 18 MeV

- Work on comparison of data with MC used in analysis ongoing, expect decrease

Final State Interactions

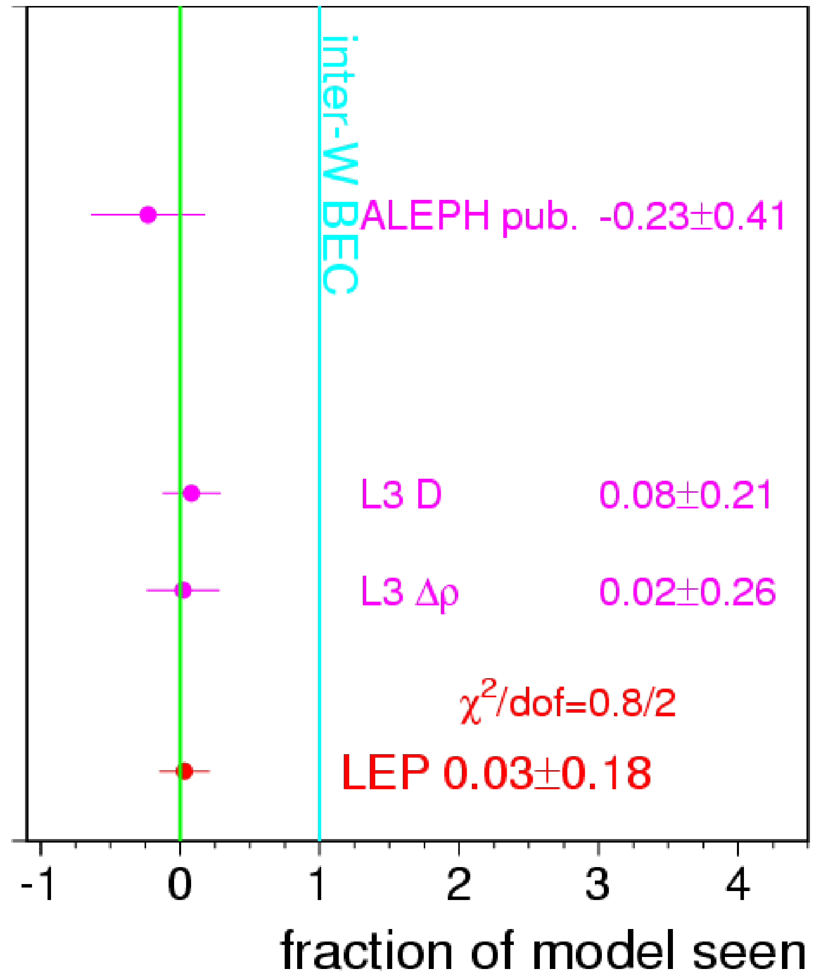


- WW decay vertices typically separated by ~ 0.1 fm, while hadronisation scale ~ 1 fm

- Two effects, possible causing miss-assignment of particles to Ws:
  - Colour Reconnection
    - Hadronisation of Ws not independent
    - Affects low momentum interjet region
  - Bose-Einstein Correlations
    - Between identical bosons (pions and kaons) close in phase space
    - Cross talk between pions from different Ws
- Only phenomenological models available!

FSI: Bose-Einstein Correlations

- Use LUBOEI model implemented in JETSET, compare MC with and without BEC.
- Uncertainty of 35 MeV (Full BE effect)
- Dedicated studies suggest BE effects between different Ws disfavoured
- Certain to be reduced by propagating limit to W mass measurement



FSI: Colour Reconnection

- Several models
  - String based (SK family, Rathsmann GAL), implemented in JETSET
  - ARIADNE – colour dipoles
  - Cluster based (Herwig)
- Typical shifts:

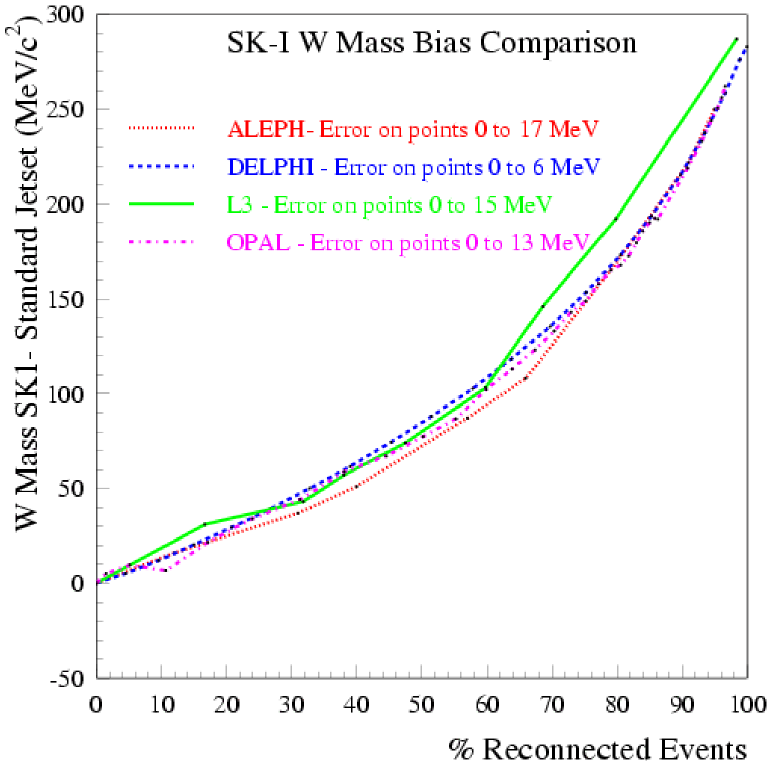
SK-I 100%	300 MeV
ARIADNE AR2	70-80 MeV
Rathsmann	40-60 MeV
Herwig	30-40 MeV

- So far only limits come from particle flow method

(See talk of E. Bouhova later)

- SK-I parameter $k_I < 2.13$, leads to mass shift of 90 MeV!

(Corresponds to ~49% reconnected events at 189 GeV)

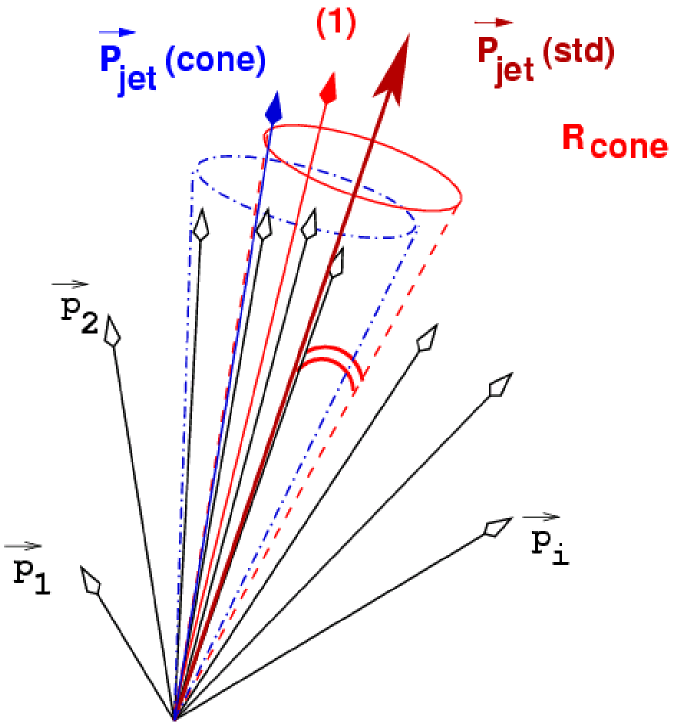


FSI: Colour Reconnection

- Use M_W to measure CR

- Expect CR to affect particles which are
  - Low momentum
  - In the interjet region

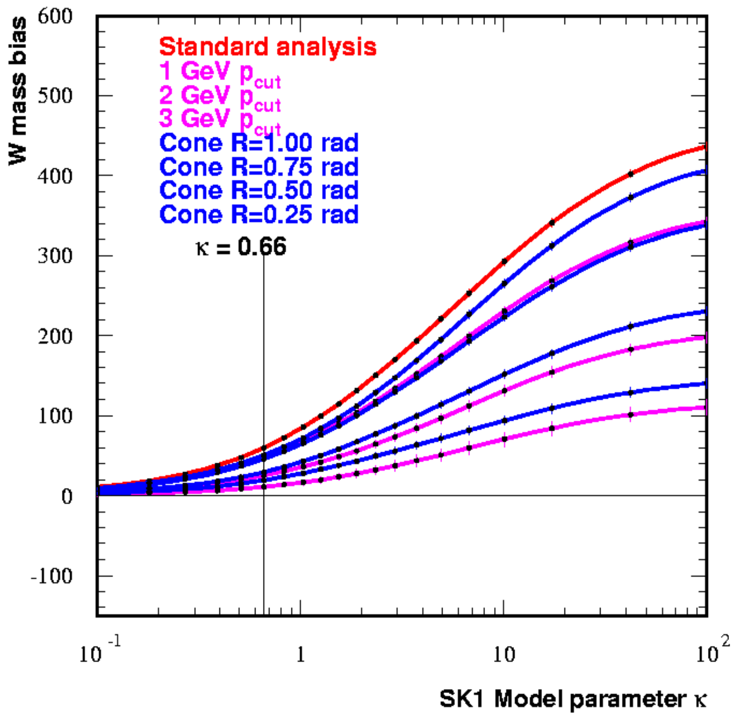
- Two methods studied
  - Remove low momentum particles from jets, P_{cut}
  - Re-compute jet angles using a cone algorithm



FSI: Colour Reconnection(DELPHI)

- Different mass estimators exhibit different sensitivity to k_I parameter:

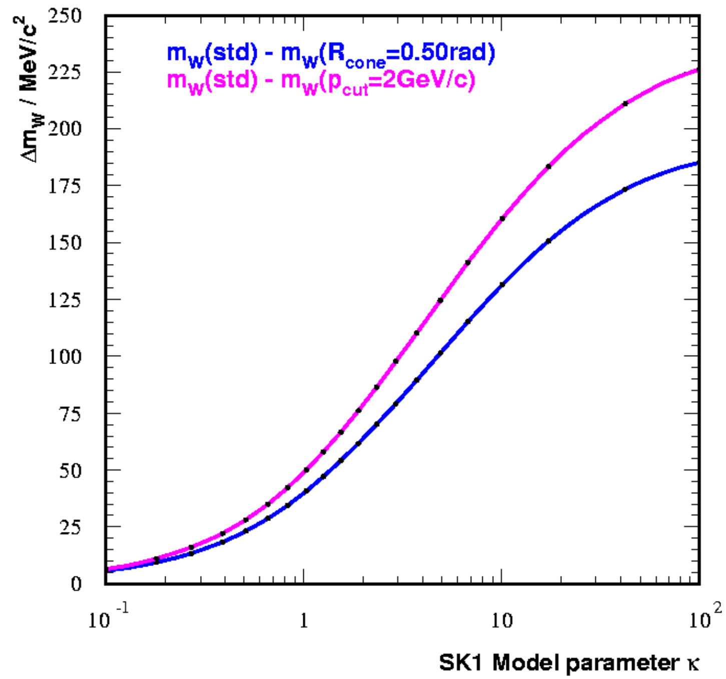
DELPHI preliminary SK1 curves



- Decrease in mass bias due to CR offset by loss of statistical precision

- Look at difference in estimators, $\delta(M_W) = M_W(\text{std})\text{-}M_W(\text{cone})$
- High correlation, uncertainty small

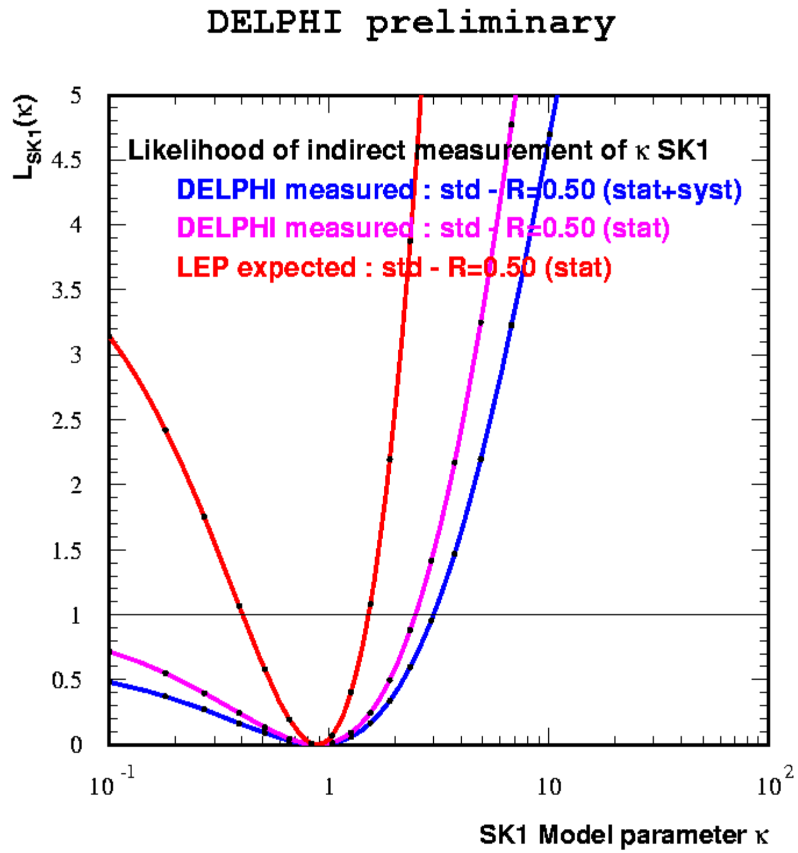
DELPHI preliminary



- Value obtained from data:
- $\delta(M_W) = 36 \pm 36 \pm 25$ MeV/c^2 (Preliminary value)

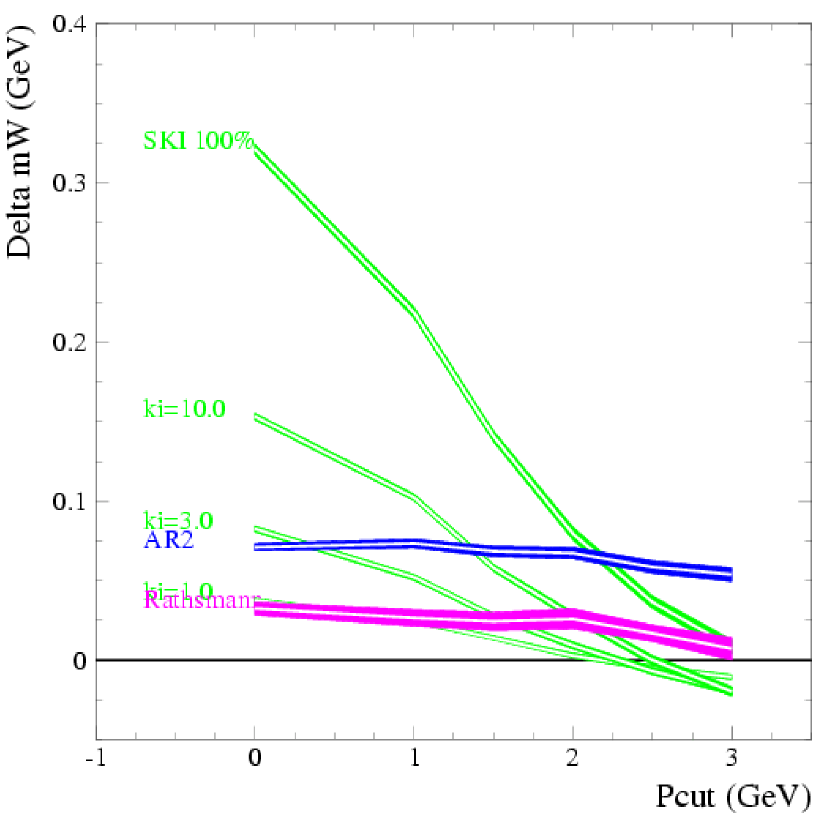
FSI: Colour Reconnection(DELPHI)

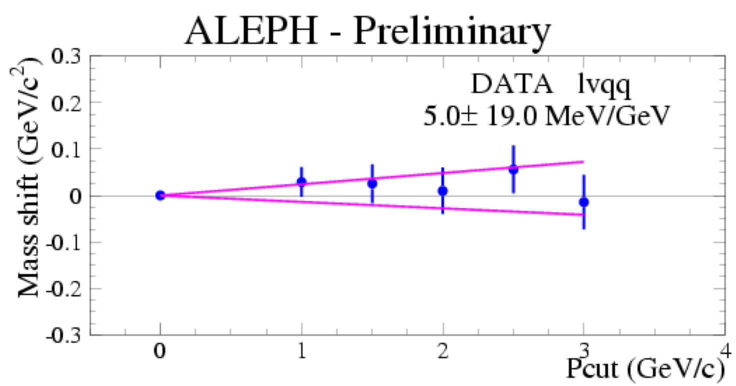
- Minimum at k_I=0.89
- Systematics studied:
  - Fragmentation
  - BE
  - Energy flow in jet
- Correlation between $\delta(M_W)$ and M_W small (11%)
- Other models predict
  - Herwig:
    - $\delta(M_W)$ = 23 ± 6 MeV/c^2
  - Ariadne:
    - $\delta(M_W)$ = 3 ± 5 MeV/c^2
- Can be combined with particle flow measurement

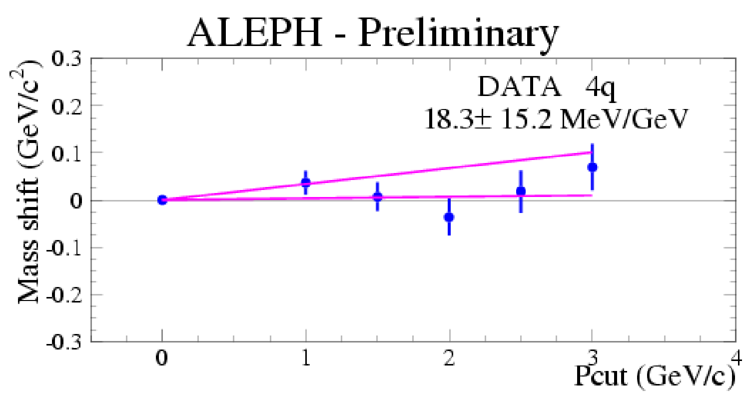


FSI: Colour reconnection (ALEPH)

- Can also use differential behaviour of W mass difference vs P_{cut} / cone radius.
- Assume linear behaviour, use slope as estimator
- Can use for other models





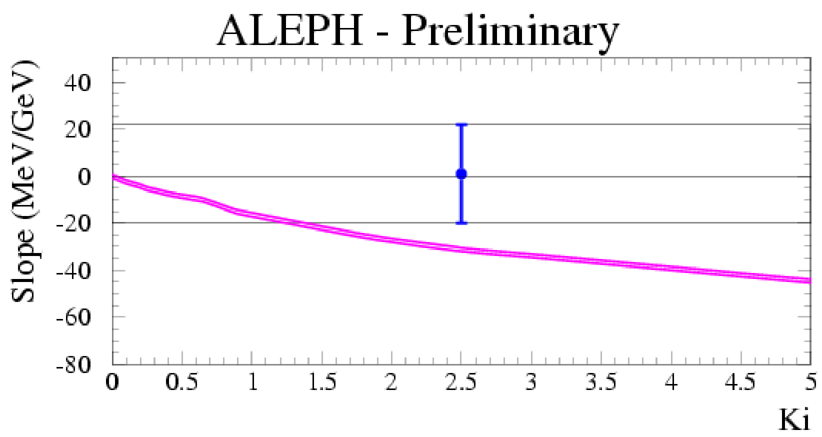


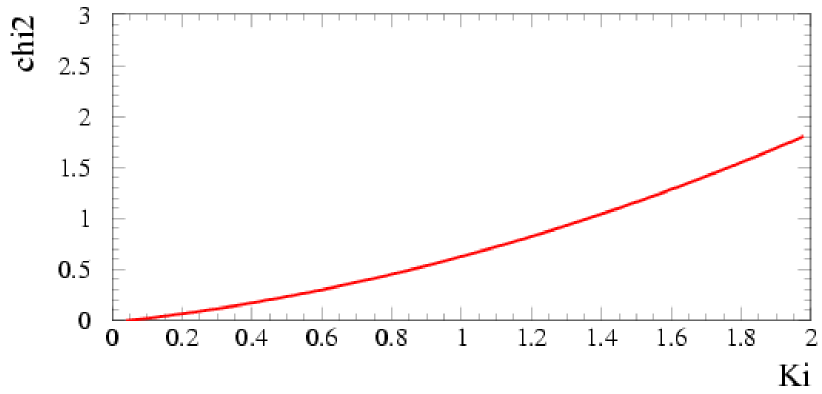
FSI: Colour reconnection (ALEPH)

- Systematics on slope:

	δ Slope (MeV/GeV)
Fragmentation	$\pm$ 6
Bose-Einstein	$\pm$ 6.5
SKI	$\pm$ 5
Total	$\pm$ 10

- Ultra conservative estimate to get upper limit on k_I
- Each systematic is treated as a bias
  - Linear sum of biases
  - Systematics added in quadrature to statistics



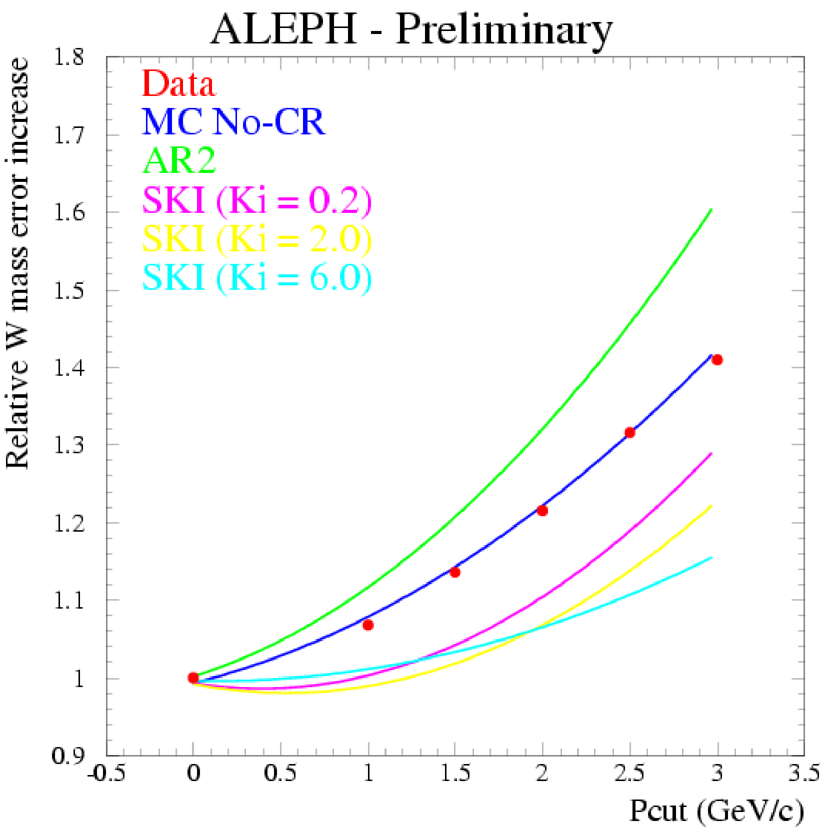


$$\Delta\chi^2 = 1 \Rightarrow K_I = 1.3\ (P_{reco} \approx 42\%)$$

FSI: Colour reconnection (ALEPH)

- CR affects the mass distribution
  - Shift of central/mean value
  - Distortion
- Mass shift vs P_{cut} gives handle on first point
- Second point can be addressed by studying variation of fitted mass error vs P_{cut}
- Provides information on other models, particularly ARIADNE 2

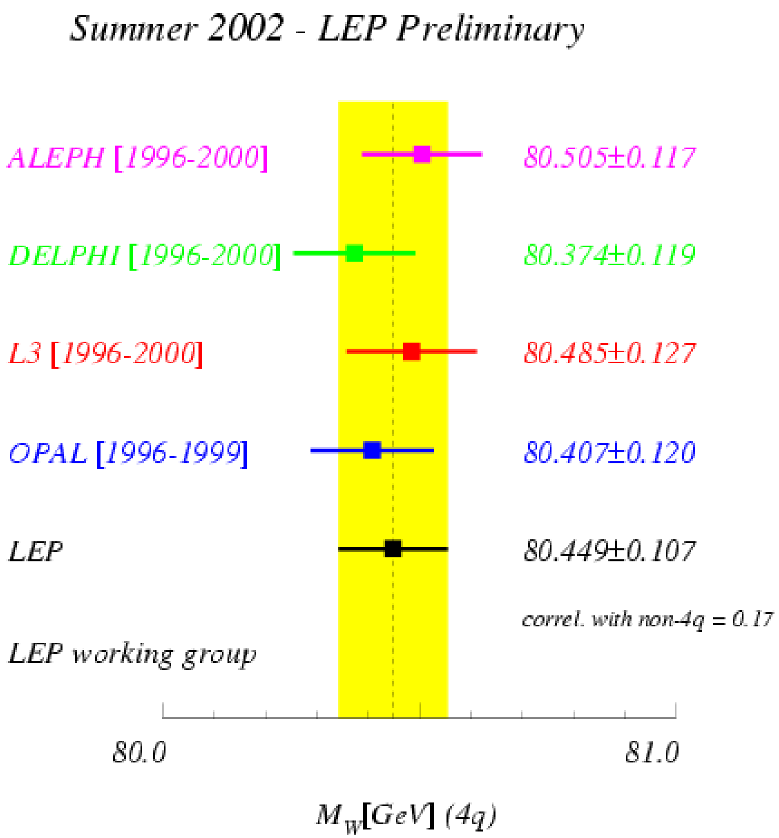
Very Preliminary!

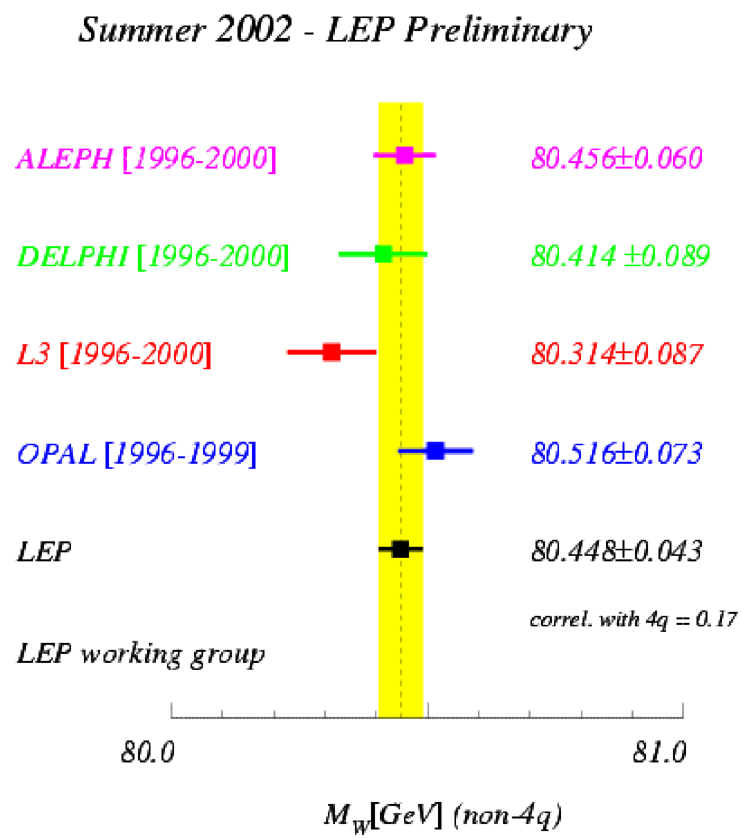


Results

qqqq: 80.449±0.107 GeV

qqlv: 80.448±0.043 GeV



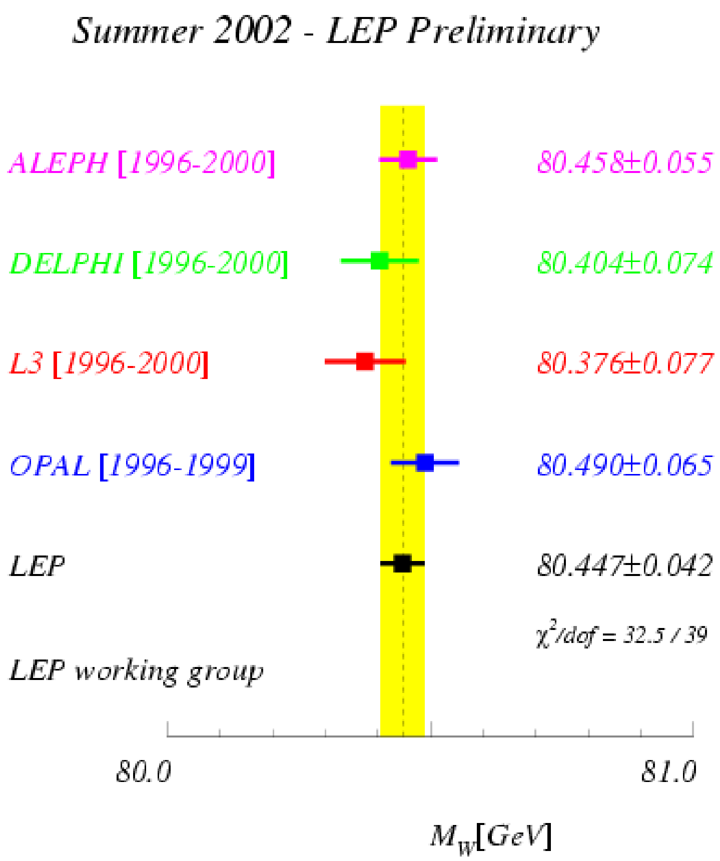


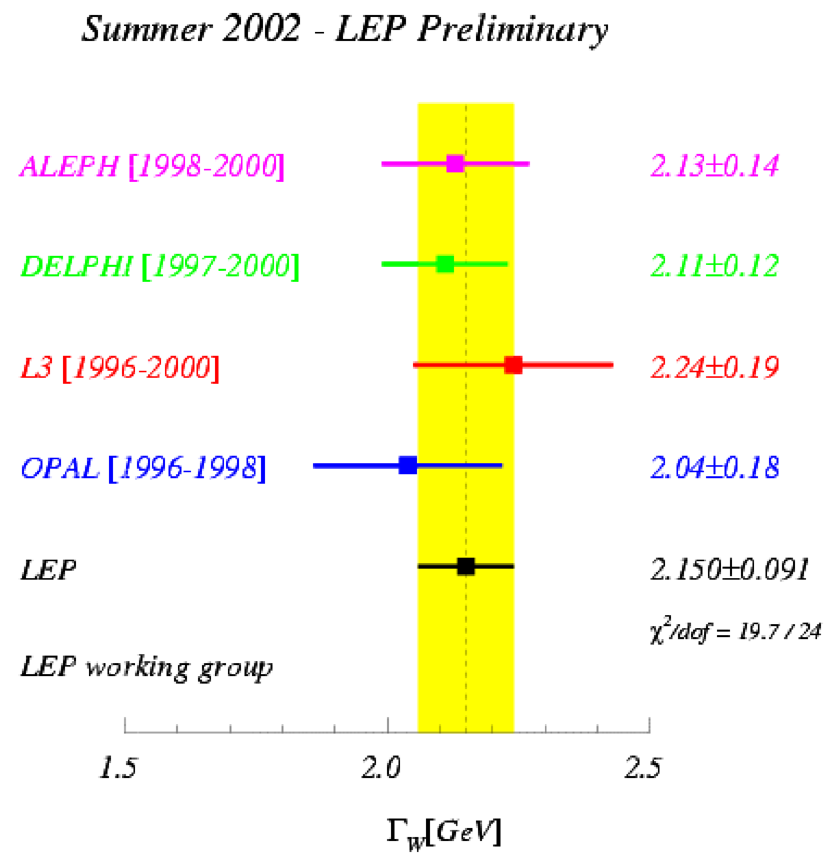
qqqq-qqlv: 9±44 MeV

Results

M_W: 80.447±0.042 GeV

Γ_W: 2.150±0.091 GeV





Outlook

- Just reduce FSI systematics:
  - Reduce CR to 40 MeV
  - BE to 5 MeV
  - Total error ~38 MeV
- Lose some stats to further reduce FSI
  - CR to 20 MeV
  - Total error ~36 MeV

- Total error of 35 MeV possible?

Summary and Outlook

- The combined preliminary LEP W mass and width measurements are:

$$M_W = 80.447 \pm 0.042 \text{ GeV}$$

$$\Gamma_W = 2.150 \pm 0.091 \text{ GeV}$$

- Future prospects:
  - Reduce FSI systematics
  - Work on fragmentation
  - LEP energy

- Match statistical error with systematics?

LEP Beam Energy

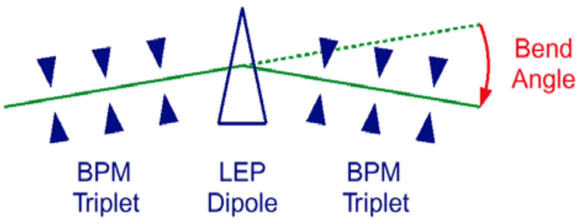
- Check extrapolation with 3 methods:

Energy Loss measurements - based on RF voltage needed to compensate for energy loss due to synchrotron radiaton

Spectrometer:

•Measure bend angle of lepton due to dipole using Beam Position Monitors

•Needs precise measurement of magnetic field



Compare peak of radiative return events with Z mass

(See talk of Chris Ainsley later)