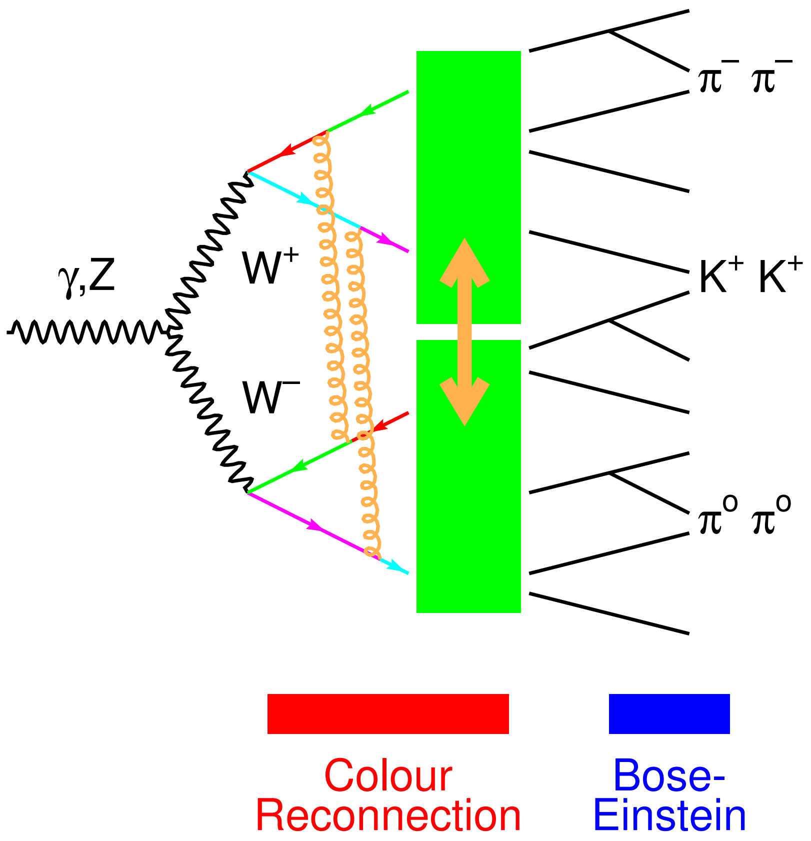
QCD and W Mass Determination at LEP

Arno Straessner
CERN

on behalf of the LEP experiments

XXXVIIIth Rencontres de Moriond
QCD and Hadronic Interactions at High Energy
Les Arcs 1800
March 23-29, 2003

- strong interactions in $e^+e^- \longrightarrow W^+W^- \longrightarrow qq\ell\nu/qqqq$:
- ▷ fragmentation and hadronisation process
- ▷ final state interaction $\longrightarrow$ Colour Reconnection (CR)
  Bose-Einstein Correlations (BEC)

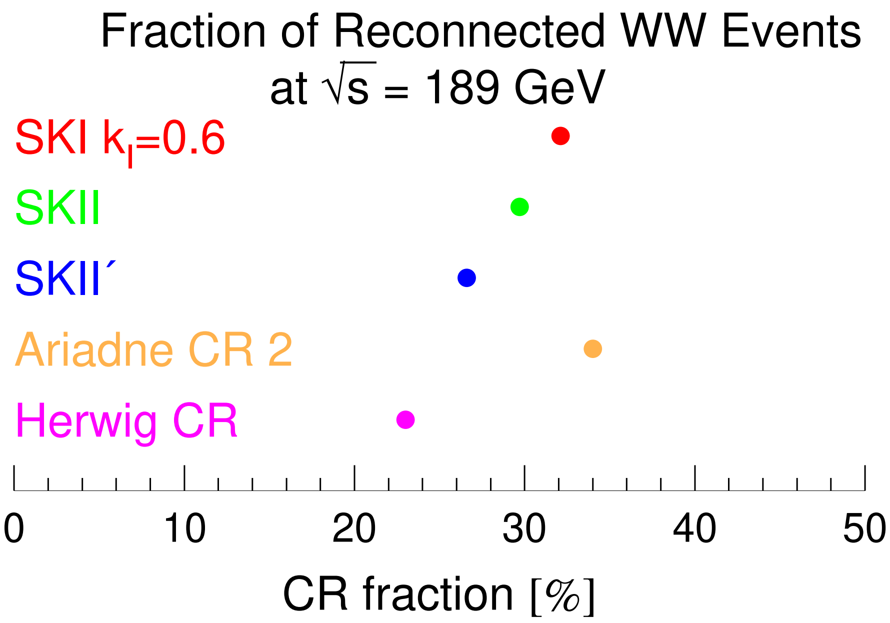


- CR main systematic effect for W mass determination in qqqq channel: $\Delta_M^{CR} = 90$ MeV
  $\Delta_M^{stat} = 35$ MeV
- weight of qqqq channel in LEP combination: 0.10

$\longrightarrow$ direct measurement of CR

Modelling of Colour Rearrangement

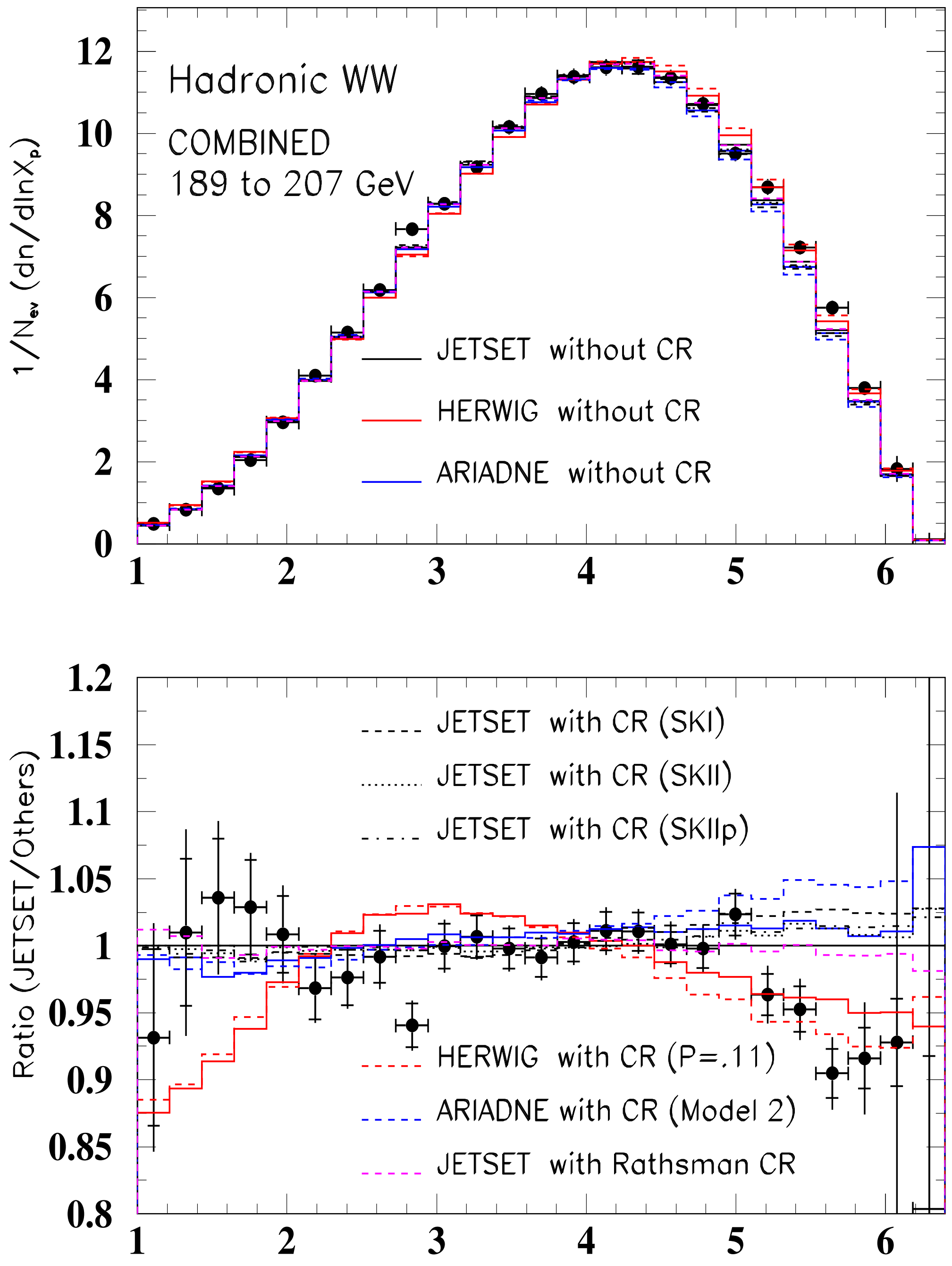
- Pythia SK I: strings $\longrightarrow$ colour flux tubes
  $\leq$ 1 reconnection for largest tube overlap f
  parameter $k_I \longrightarrow P_{reco} = 1 - \exp(-f \cdot k_I)$
- Pythia SK II: strings $\longrightarrow$ vortex lines
  reconnection if lines cross
- Pythia SK II': like SK II plus condition that
  string length is reduced
- Pythia GAL: generalised area law (Rathsman)
  string area difference ΔA
  $P_{reco} = R_0 \, [1 - \exp(-b \cdot \Delta A)]$
  rapidity gaps in $q\bar{q}g \longrightarrow R_0 < 0.02$ (Opal,L3)
- Ariadne CR 2: reconnection allowed
  - after cascade evolved down to 2 GeV $\approx \Gamma_W$
  - if string length reduced
- Herwig CR: cluster rearranged if
  space-time extension reduced



- tuning to Z peak data for GAL, Ariadne CR and Herwig CR

Charged Particle Multiplicity

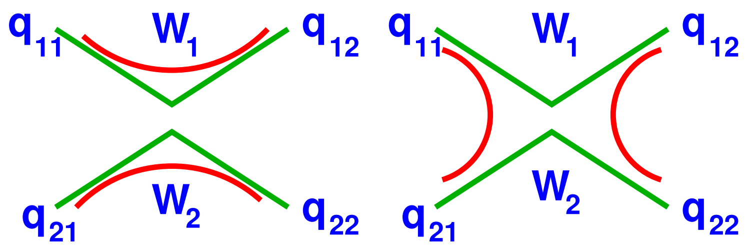
- CR changes string length and configuration
  → influence on particle multiplicity
- most recent measurement by Aleph with all LEP2 data:



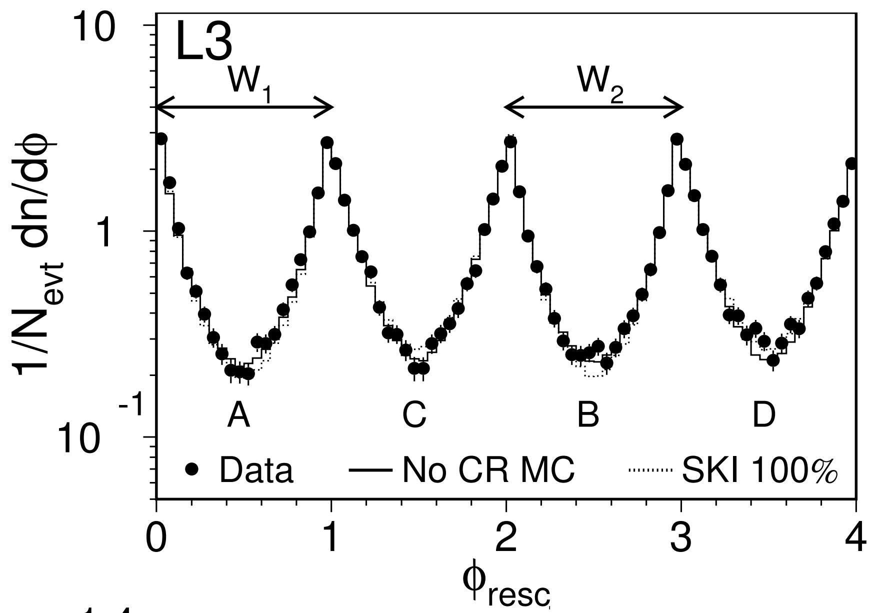
$\xi = -\ln(2p/\sqrt{s})$

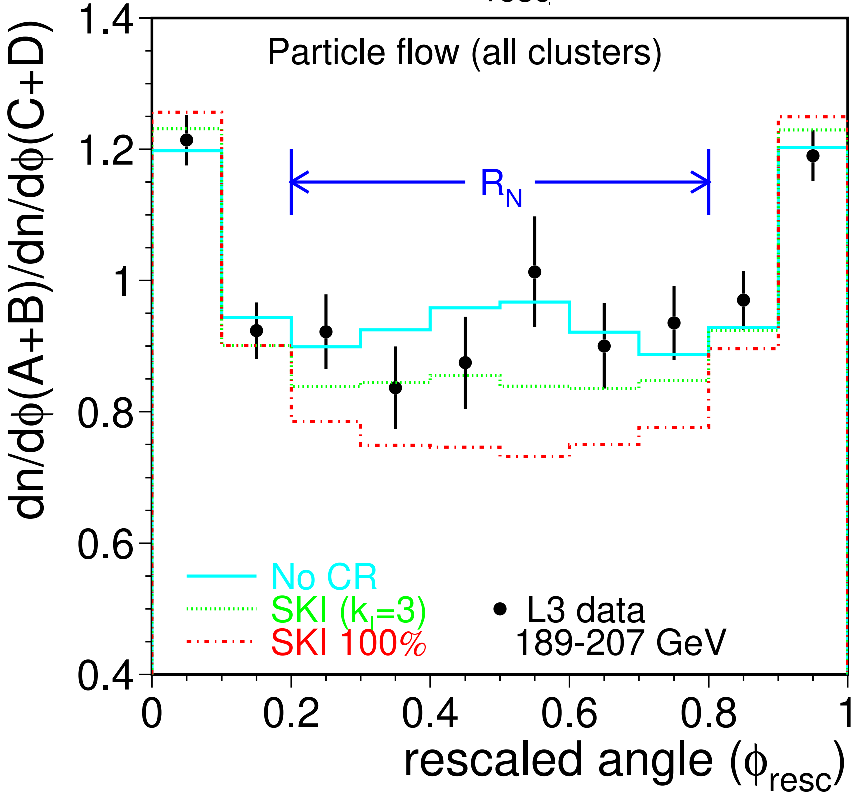
- only small effect from CR
→ larger differences between fragmentation models
- similar for average multiplicities

- from simple CR picture



→ CR changes inter-jet activity

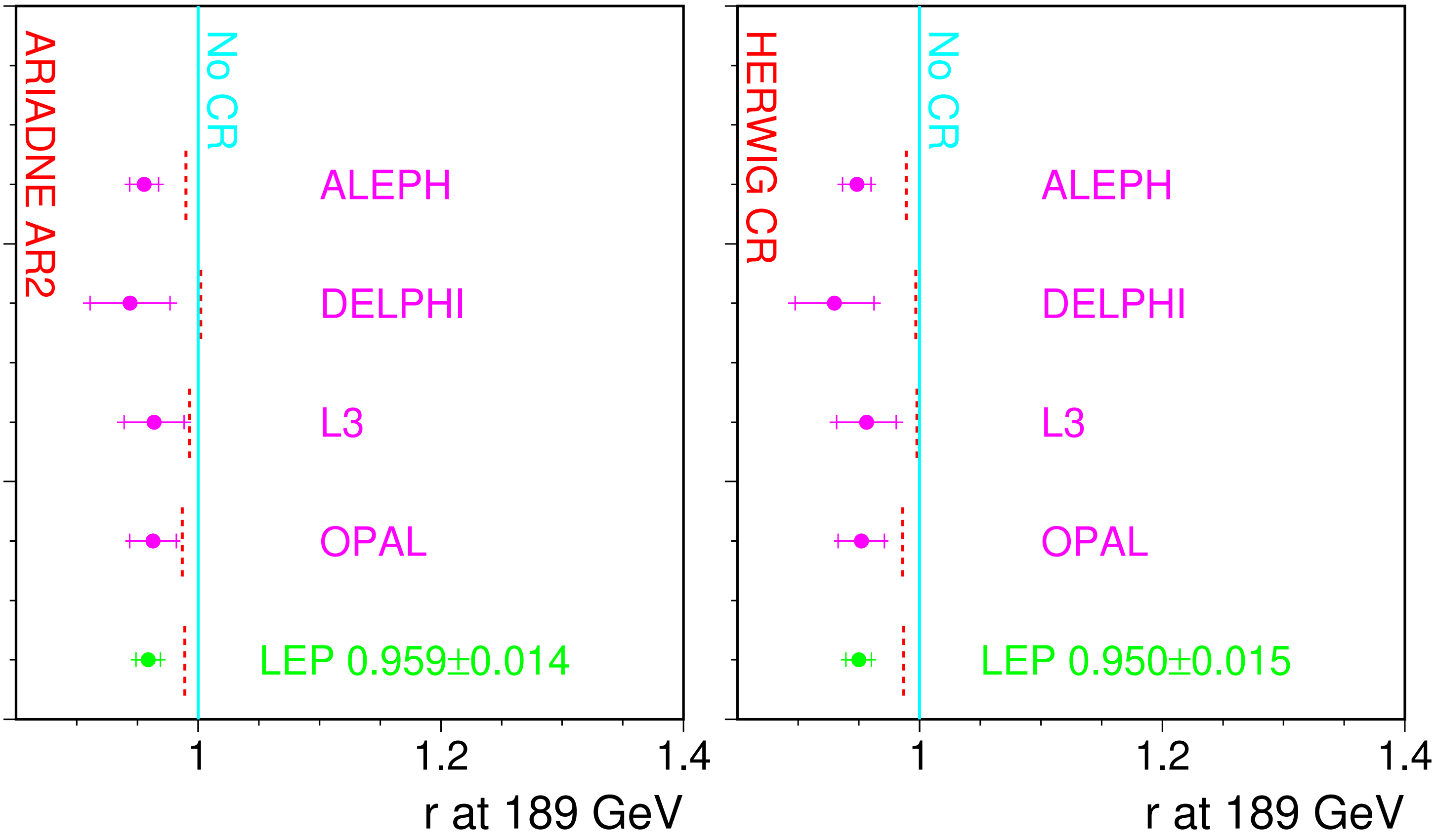




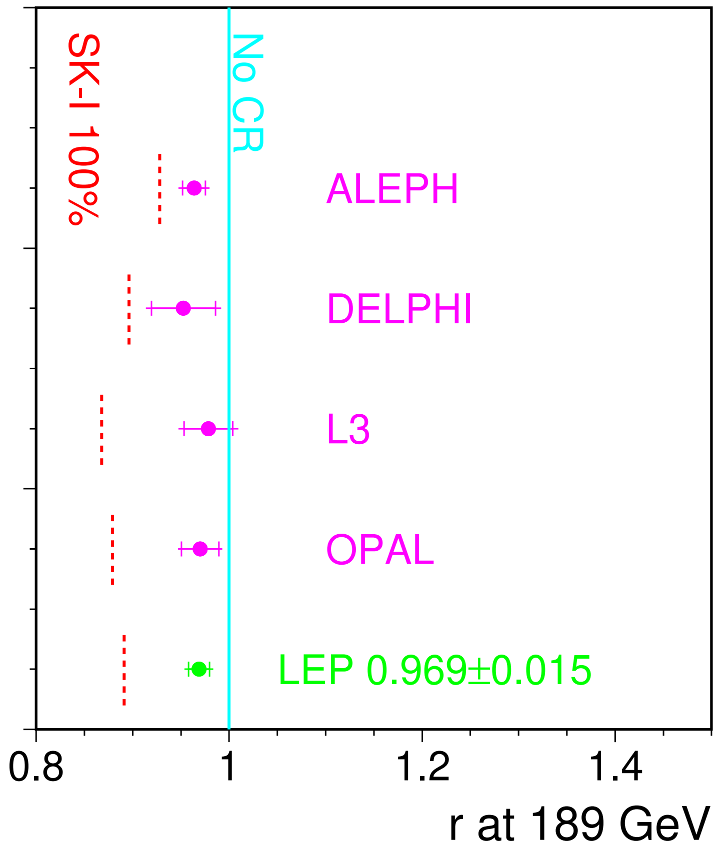
- integrate particle flow in intra-W (A+B) and inter-W (C+D) region → ratio R_N

CR with Particle Flow

- for combination: normalize to $r = R_N^{data} / R_N^{no-CR}$
- CR effects increase with $\sqrt{s} \longrightarrow$ rescale to 189 GeV
- Ariadne CR 2 and Herwig CR:

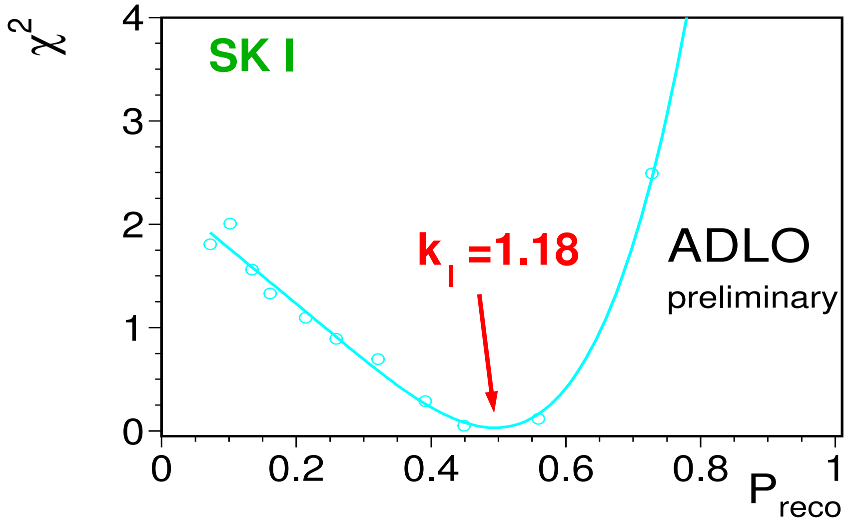


- distance between CR and no-CR $\longrightarrow$ sensitivity
- r_{data} smaller than predicted by Ariadne or Herwig
- main systematic uncertainties from
  - ▷ hadronisation modelling (0.0081)
  - ▷ background (0.0031), mainly $e^+e^- \longrightarrow q\bar{q}gg$ shape and scale

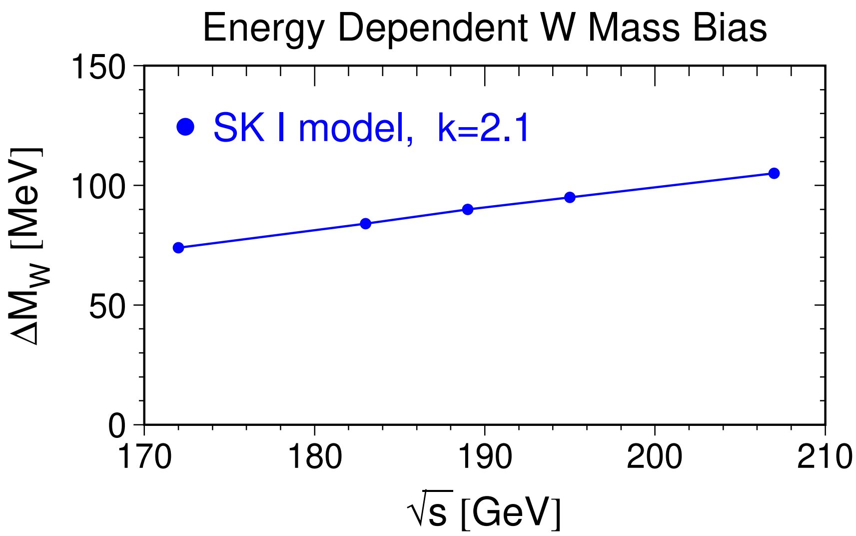


- SK1 with 100% reconnection disfavoured with 5.2σ

$\longrightarrow$ fit for model parameter k_I



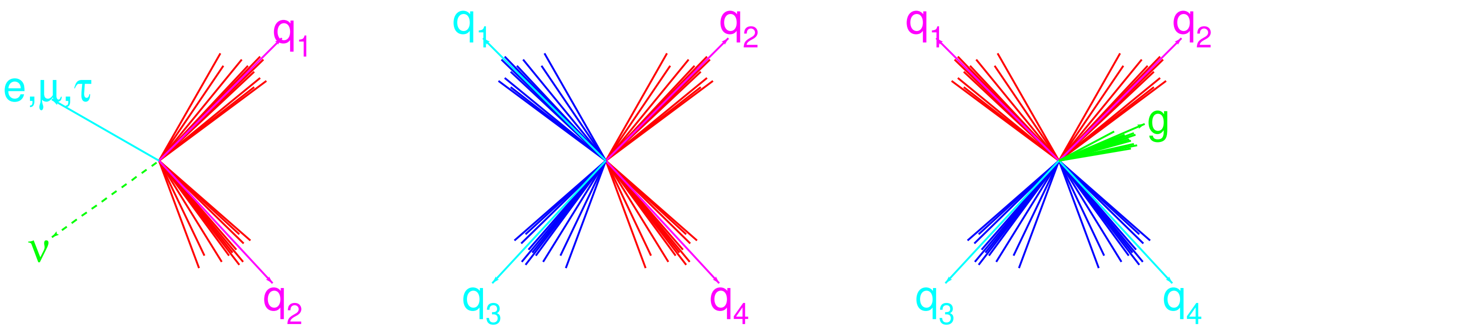
- $0.39 < k_I < 2.13$ at 68% CL
- no-CR scenario can not be ruled out

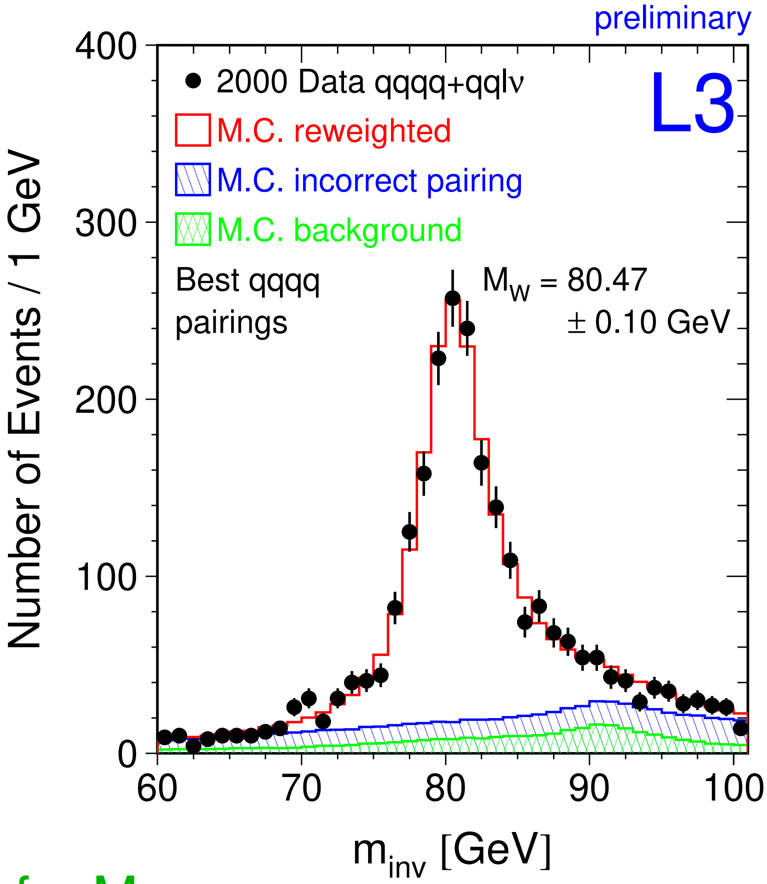


- predicted mass bias for maximal k_I:

M_W Extraction Method

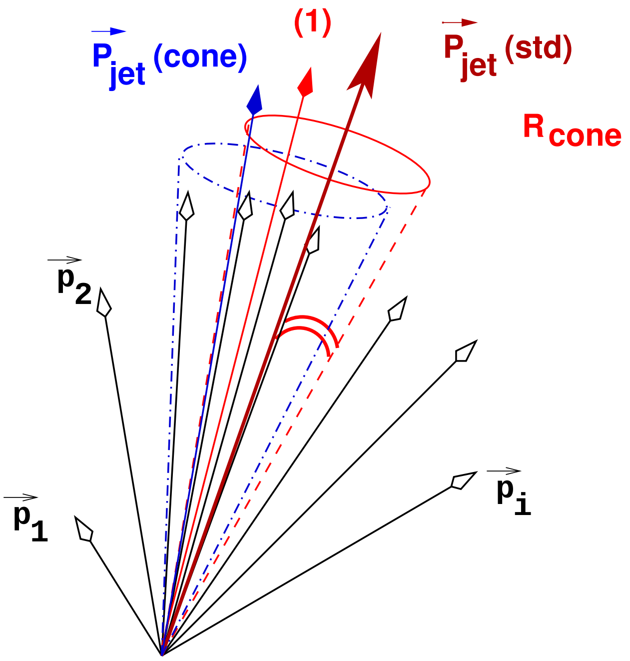
- standard analysis: reconstruct final state leptons
  cluster jets from remaining particles
- qqqq and $qq\ell\nu$ channel $\longrightarrow$ invariant masses $M_{qq(g)}$, $M_{\ell\nu}$

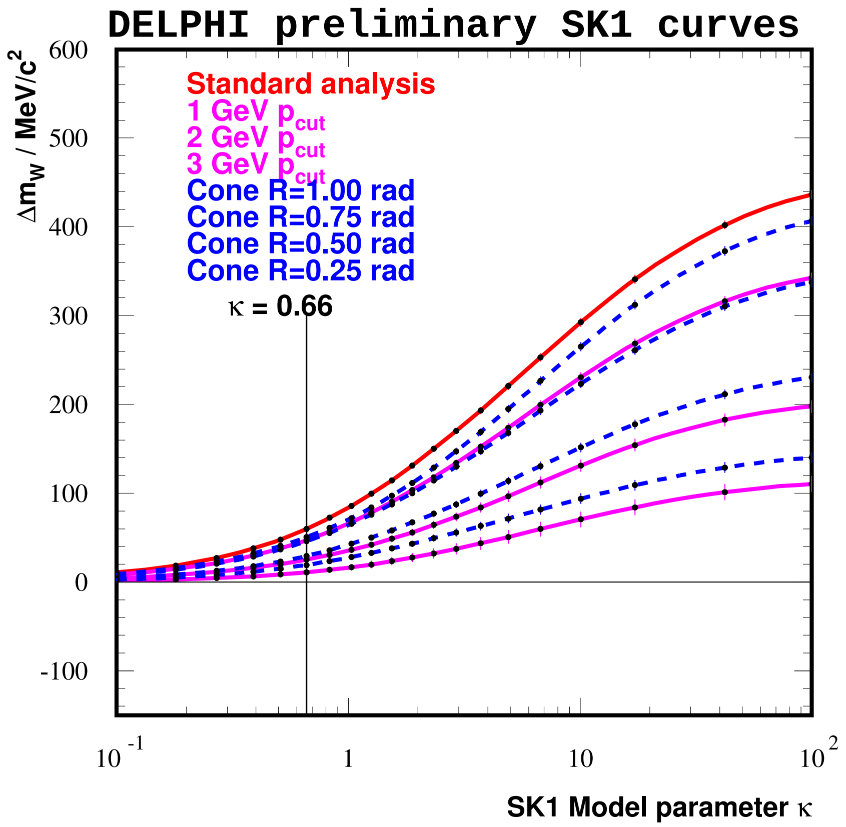




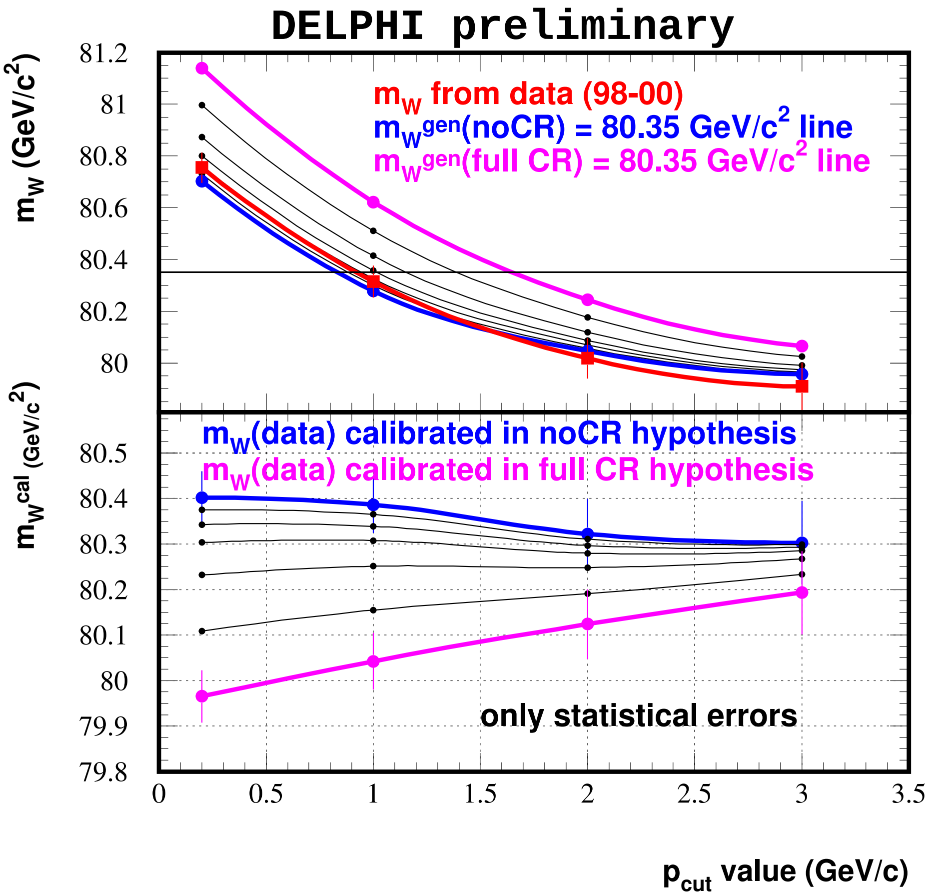
- constrained fit:
  $\Sigma E_i = \sqrt{s}$
  $\Sigma \vec{p}_i = 0$
  $M_{W,1} = M_{W,2}$
- maximum likelihood fit for M_W
  $\longrightarrow$ MC reweighting or convolution technique
- in absense of systematics:
  statistical precision of qqqq: 28 MeV, better than $qq\ell\nu$
- large bias from CR $\longrightarrow$ up to 105 MeV at highest $\sqrt{s}$

- reduce CR bias: ▷ remove low energy particles $\longrightarrow p_{cut}$
  ▷ hybrid cone algorithm



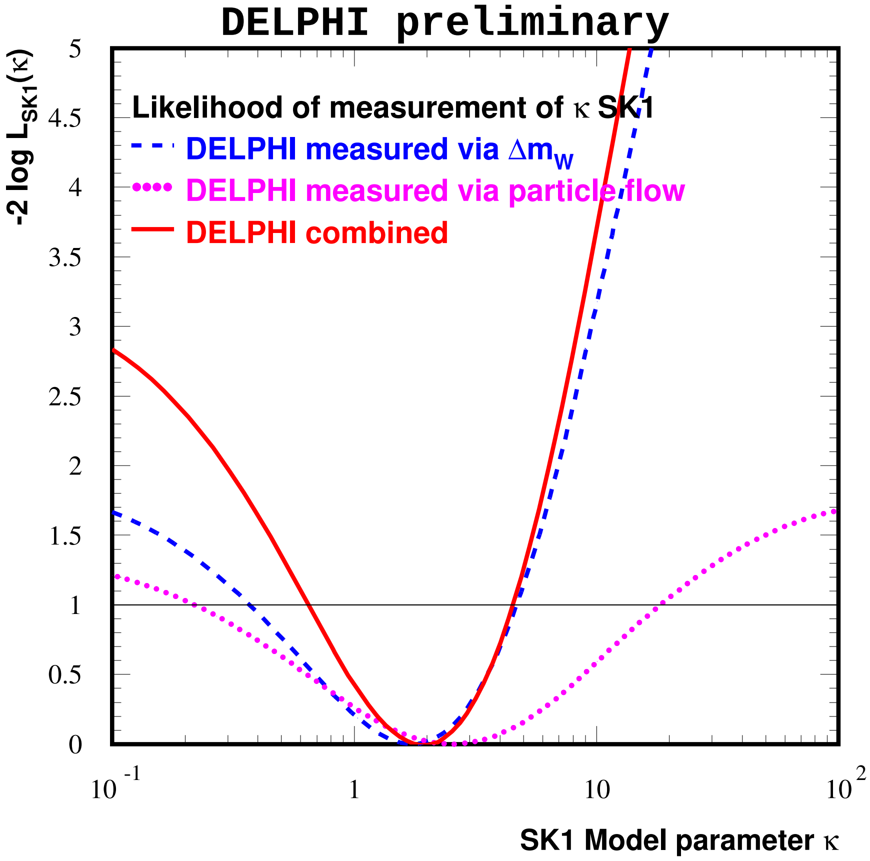


- turn it into a CR measurement:

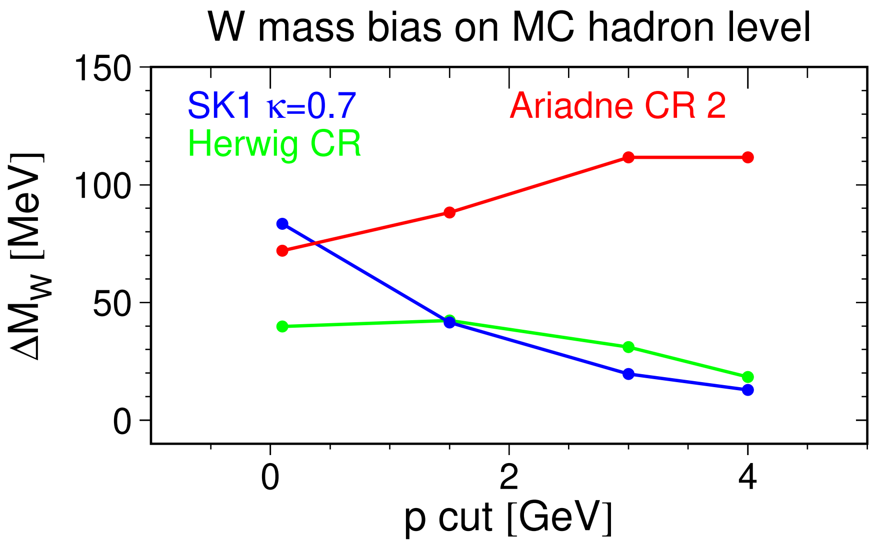


- CR from particle flow: $\varepsilon_{qqqq} = 12\%$, $\pi_{qqqq} = 90\%$
- modified M_W-estimator: $\varepsilon_{qqqq} = 88\%$, $\pi_{qqqq} = 80\%$

$\longrightarrow$ uncorrelated $\longrightarrow$ combined:



- M_W-shift better sensitivity than particle flow
- all experiments working on similar analyses
- caveat: Ariadne CR does not behave as "expected":



- a problem with the gluon energy parameter

$\longrightarrow$ working on correction

- colour reconnection:
  - ▷ all measurements with standard M_W estimator
  - ▷ uncertainty from M_W bias for SKI with $k_I = 2.1$ from particle flow measurement
  - ▷ $\sqrt{s}$-dependent

$\longrightarrow$ 90 MeV in qqqq channel

- Bose-Einstein correlations:
  - ▷ comparison of intra-W BEC with inter-W BEC and/or no-BEC Monte Carlo samples
  - ▷ direct BEC measurements not yet consistently taken into account

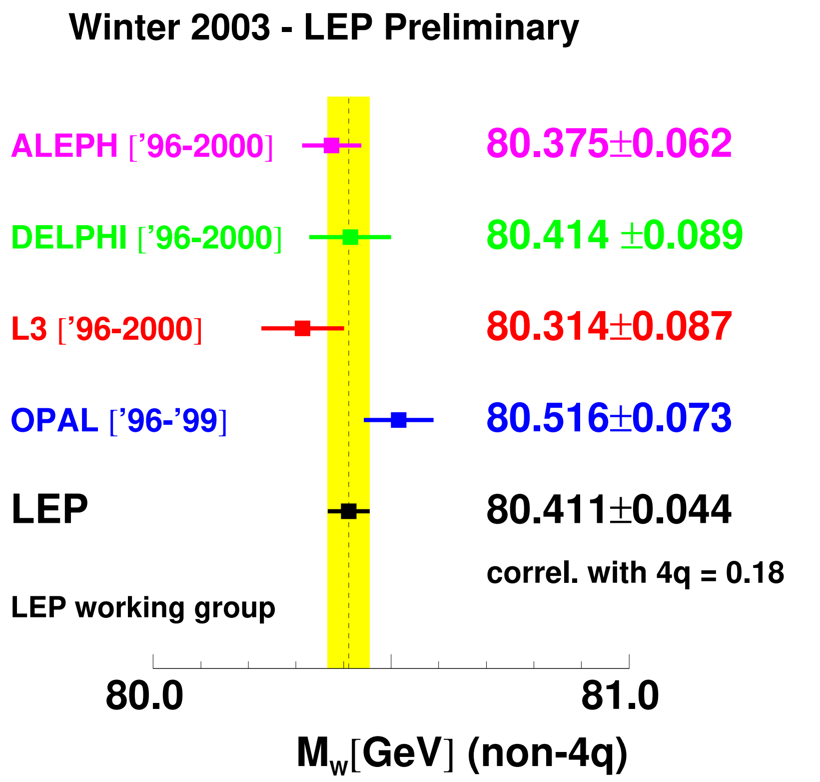
$\longrightarrow$ 35 MeV in qqqq channel

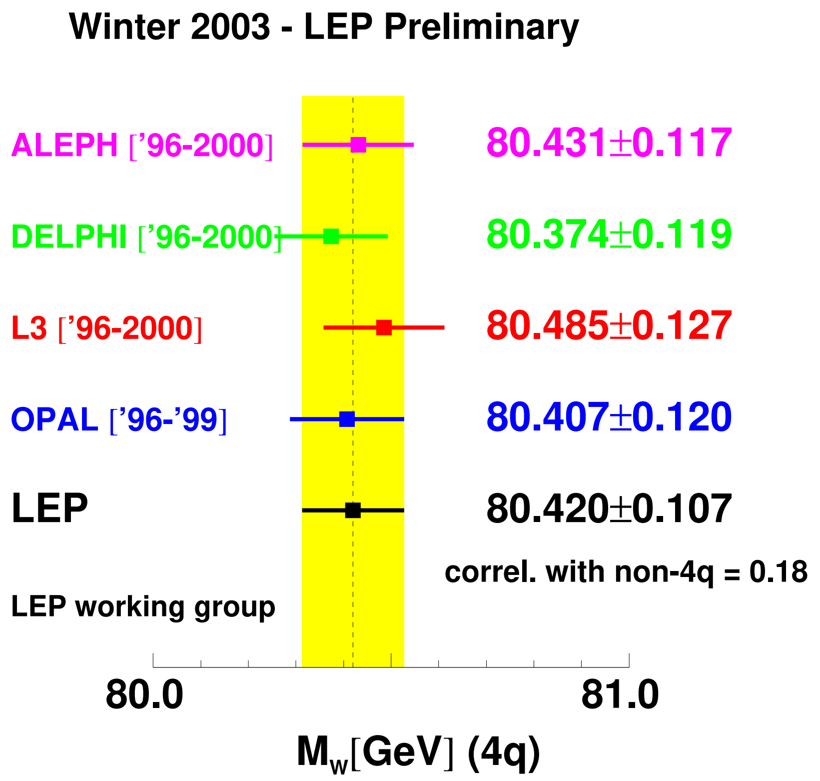
- hadronisation:
  - ▷ compare hadronisation models: Pythia, Herwig and Ariadne
    $\longrightarrow$ different parameter tunings by experiments
    $\longrightarrow$ different levels of agreement
  - ▷ variation of tuning parameters

$\longrightarrow$ 18 MeV in qqqq and 19 MeV in qq$\ell\nu$ fully correlated

Source	Systematic Uncertainties on M_W in MeV		
	$qq\ell\nu$	qqqq	combined
Colour Reconnection	–	90	9
BE Correlations	–	35	3
Hadronisation	19	18	18
ISR/FSR	8	8	8
Detector Syst.	14	10	14
LEP Beam Energy	17	17	17
Other	4	5	4
Total Systematic	31	101	31
Statistical	32	35	29
Total	44	107	43
Statistical w/o Systematics	32	28	21

- including updated measurements from Aleph:

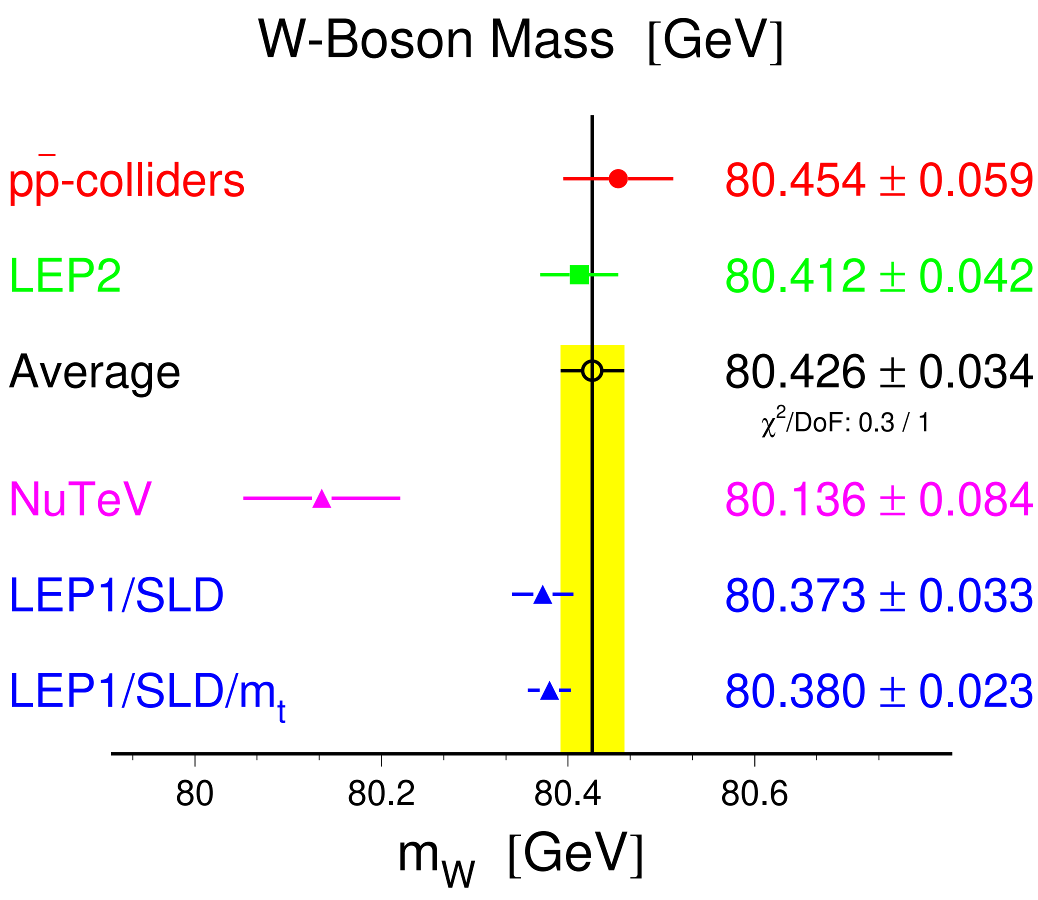




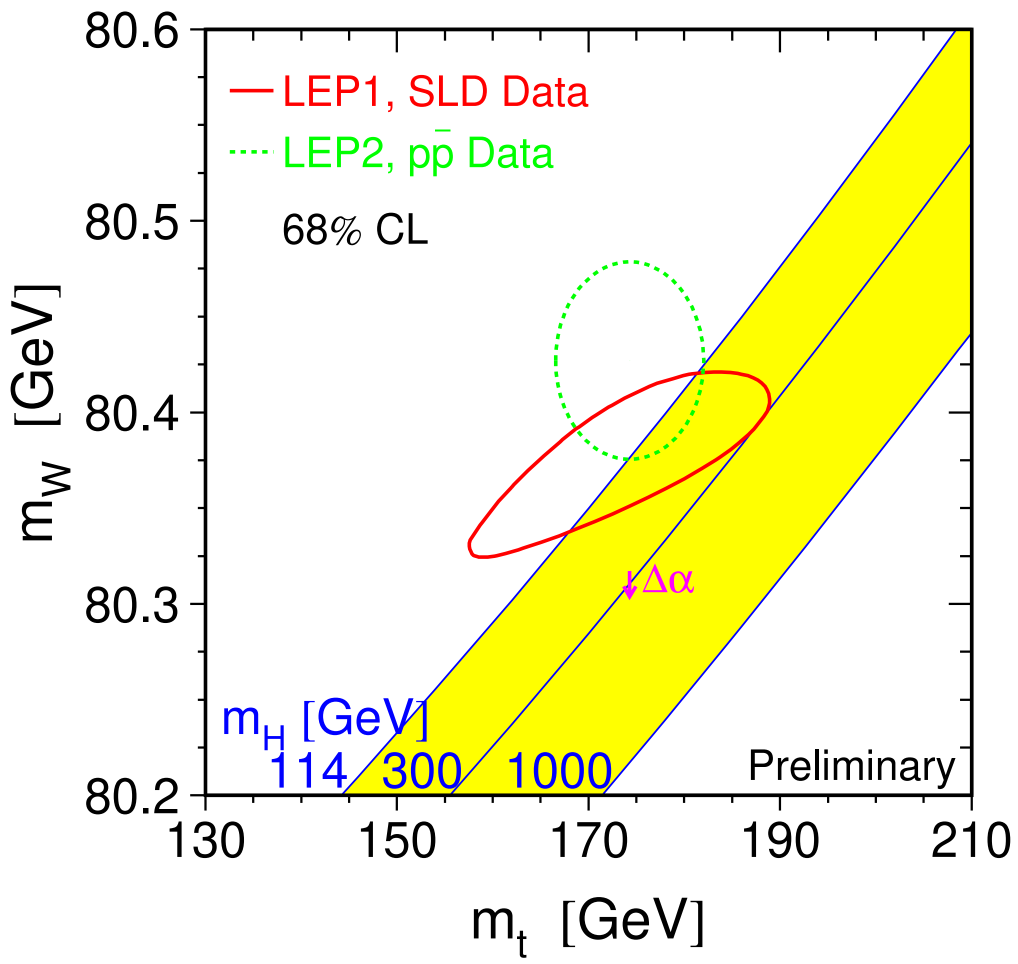
- W mass difference, excluding FSI systematics:

$$\Delta M_W(qqqq - qq\ell\nu) = +22 \pm 43 \text{ MeV}$$

All Channels Combined



- Standard Model fit to all measurements except M_W and M_t:



- direct measurement of CR ongoing

▷ extreme CR scenarios ruled out

▷ data prefers small CR but not incompatible with no-CR

- important for LEP W mass measurement:

$$M_W = 80.412 \pm 0.042 \text{ GeV}$$

. . . in good agreement with fit to electroweak data

- uncertainties on M_W will improve until final result