W^+W^- Hadronic Decay Properties

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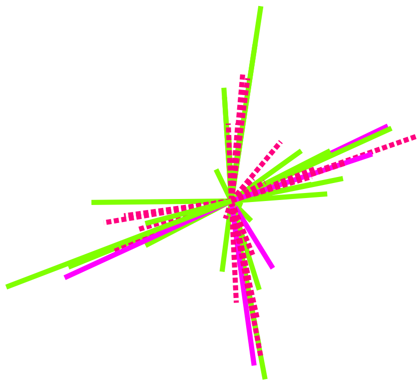
All data preliminary, $\sqrt{s} \sim 183$ GeV,
$\int \mathcal{L}\mathrm{dt} \sim 55$ pb^{-1}/experiment

OUTLINE

- Motivation
- Event properties
- Heavy hadrons
- M_{W} biases
- Summary

Motivation



$\mathrm{W}^+ - \mathrm{W}^-$ decay vertices $\sim$ 0.1 fm

hadronic scale $\sim$ 1 fm

$\Rightarrow$ large spacetime overlap

Two colour singlets, may not fragment independently

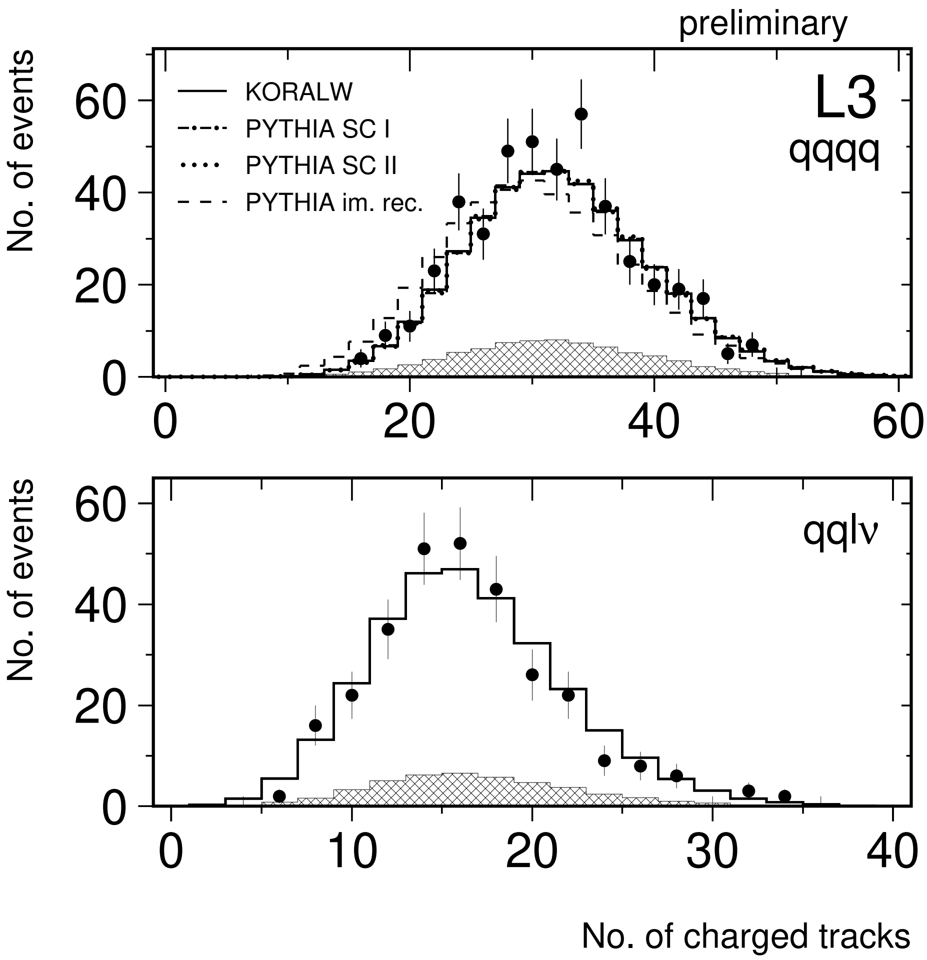
$\Rightarrow$ 'colour reconnection' (CR)

May affect M_{W} measurement

- Perturbative CR estimated negligible, LEP2 regime
- Non-perturbative domain
  - reconnection when hadronisation regions overlap
  - spacetime picture of shower development important
- Charged particle and event shapes
  - some sensitivity to CR effects
  - insight to QCD vacuum structure, hadronisation
  - control systematics on M_{W} measurement

Charged Particle Multiplicity

Construct $\Delta\langle n_{\rm ch}\rangle = \langle n_{\rm ch}^{\rm 4q}\rangle - 2\langle n_{\rm ch}^{{\rm qq}\ell\nu}\rangle$

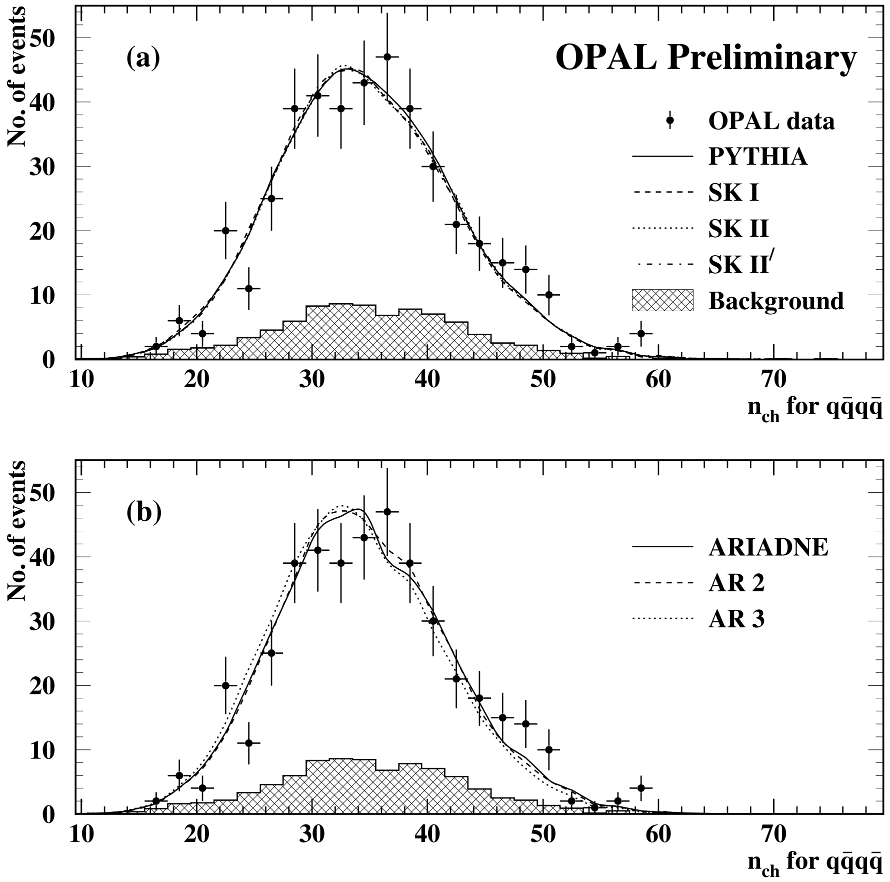


uncorrected data with CR models

Extract charged multiplicity from:

- direct measurement
- $\int$ fragmentation function, rapidity distribution

Charged Particle Multiplicity



uncorrected data with CR models

Typical model predictions for $\Delta\langle n_{\mathrm{ch}}\rangle$ small

- Sjöstrand-Khoze(SK) I ~ -0.3
- SK II, SK II′ ~ -0.2
- ARIADNE 2 ~ -0.1
- AR 3 ~ -1.0

One approach:

- unfold for detector response, selection, ISR
- add systematics from unfolding with CR models

Charged Particle Multiplicity

Expt.	$\langle n_{\rm ch}^{\rm 4q} \rangle$	$\langle n_{\rm ch}^{{\rm qq}\ell\nu} \rangle$	$\Delta\langle n_{\rm ch} \rangle$
A*	35.33 ± 0.73	17.01 ± 0.37	$+1.31 \pm 0.83$
D	37.36 ± 1.00	19.48 ± 0.73	-1.6 ± 1.5
L	36.3 ± 0.9	18.6 ± 0.6	-1.0 ± 0.9
O	39.4 ± 1.0	19.3 ± 0.4	$+0.7 \pm 1.0$

* Not unfolded to full acceptance

All errors are stat.+syst.

average $\Delta\langle n_{\rm ch} \rangle = +0.20 \pm 0.50 ({\rm stat.} + {\rm syst.})$

All Sjöstrand-Khoze, ARIADNE, HERWIG models still consistent with data, some extreme models disfavoured

Ellis-Geiger model studied by ALEPH and OPAL, found:

- before unfolding, $\langle n_{\rm ch}^{\rm 4q} \rangle \sim 2$ units higher than data,
  r.m.s. ~ 1.7 units broader
- no angular dependence observed in $\Delta\langle n_{\rm ch} \rangle$
- very high charged multiplicity, e.g. $\langle n_{\rm ch}^{\rm 4q} \rangle > 50$
- current model implementation does not reproduce large $\Delta\langle n_{\rm ch} \rangle$ predictions in any colour scenario

$\Rightarrow$ do not use current Ellis-Geiger model for $M_{\rm W}$ systematics

Charged Particle Dispersion

Shape of multiplicity distribution also studied

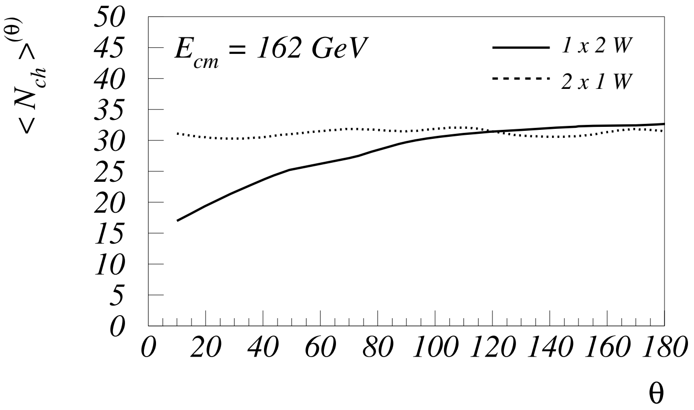
Construct $\Delta \mathrm{D} = \mathrm{D}^{4\mathrm{q}} - \sqrt{2}\mathrm{D}^{\mathrm{q\overline{q}}\ell\overline{\nu}_\ell}$

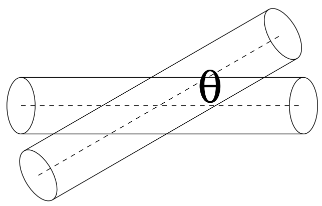
Expt.	$\langle n_{\mathrm{ch}}^{4\mathrm{q}} \rangle$	$\langle n_{\mathrm{ch}}^{\mathrm{qq}\ell\nu} \rangle$	$\Delta \langle n_{\mathrm{ch}} \rangle$
D	8.24 ± 0.51	5.76 ± 0.49	$+0.09 \pm 0.84$
O	8.8 ± 0.7	6.1 ± 0.5	$+0.2 \pm 0.6$

All errors are stat.+syst.

No indication for difference at present

Event Properties



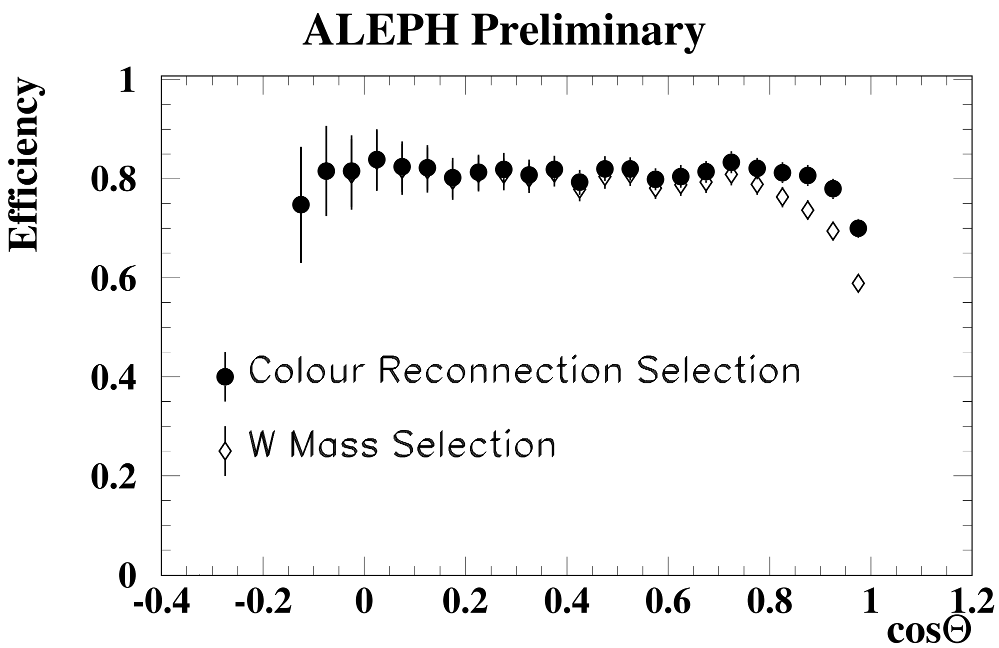


Predicted effects largest when $q\overline{q}$ pair axes parallel, high T

To correct or not? Model dependence important.

Currently:

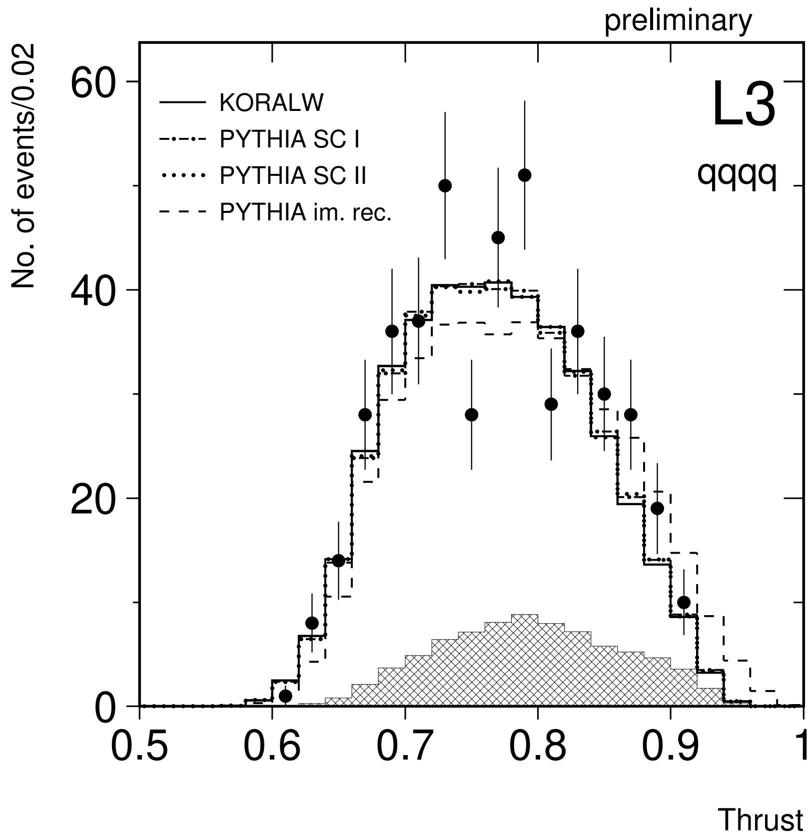
- A: no unfolding for topological biases, $P < 0.2\,\mathrm{GeV}$
- D: unfold
- L,O: unfold, add systematic from unfolding with CR models



MC study

Check selection efficiency as $q\overline{q}$ opening angle, θ

Thrust



Uncorrected data

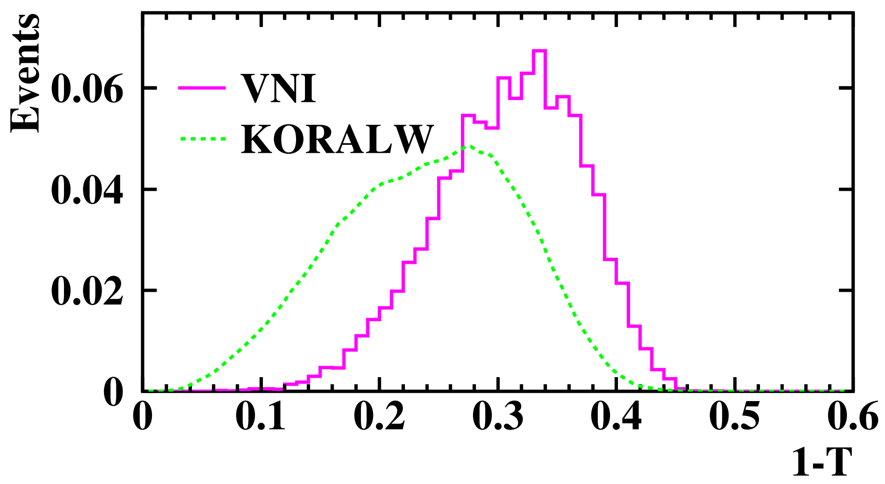
Perturbative CR (toy) model taken as upper limit

Sjöstrand-Khoze models do not require additional tuning

ARIADNE and HERWIG must be retuned

Ellis-Geiger model not tuned to describe Z^0 data

W^+W^- events more spherical than other MCs, e.g.

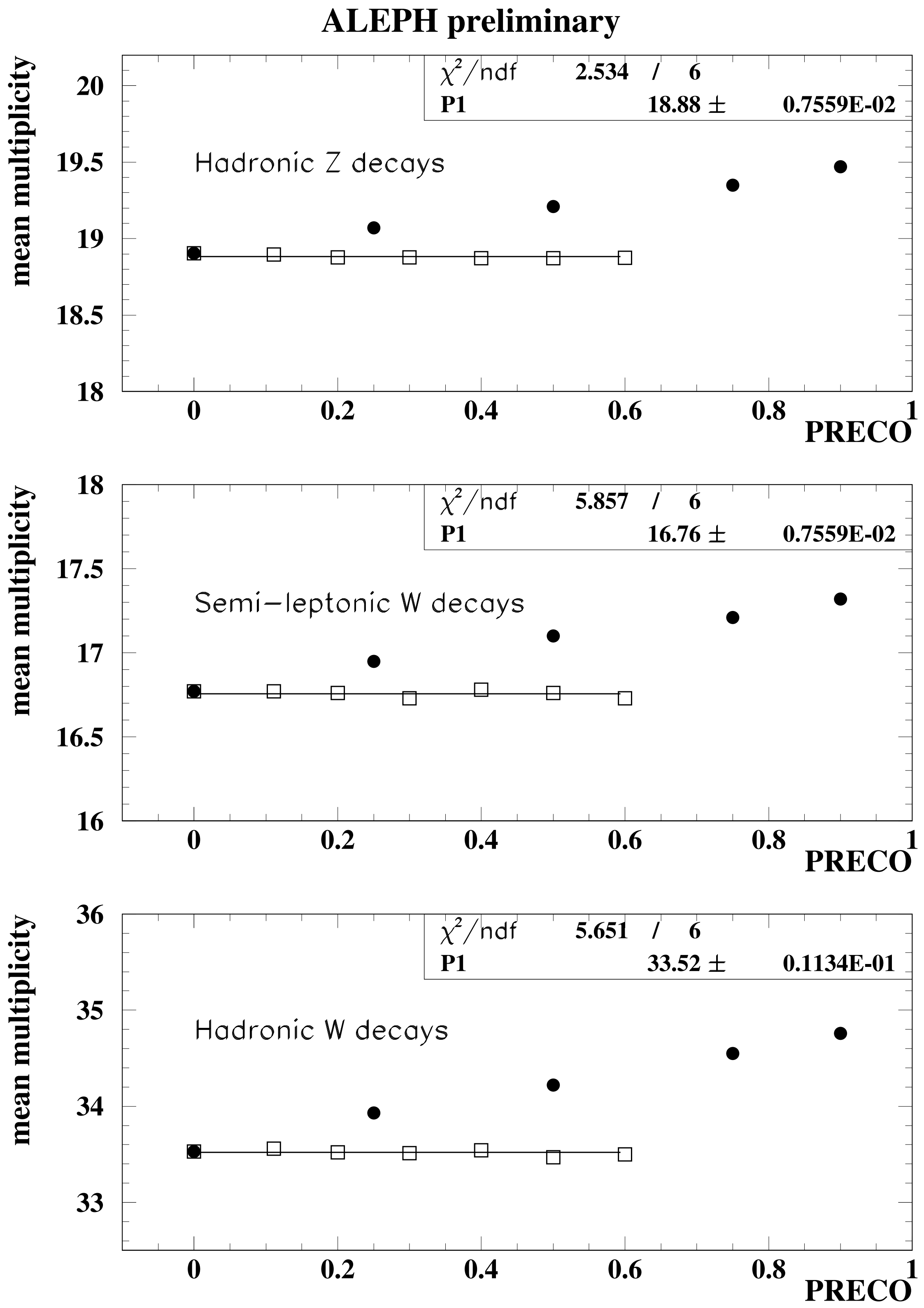


hadron level MC study

Expect such events well within acceptance of the detector

Model Tuning

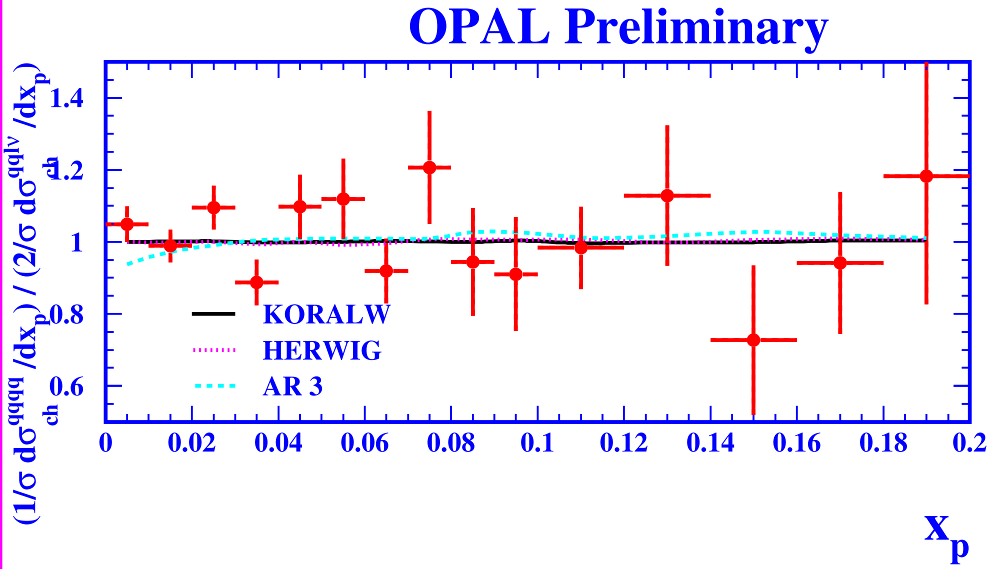
Model tuning essential for reliable conclusions, e.g. HERWIG



Retuning at any given PRECO allows good description of data

Alternative Observables

Ratio of x_p $\quad (\mathrm{W^+W^-} \to \mathrm{q\bar{q}q\bar{q}}) / (2\mathrm{W^+W^-} \to \mathrm{q\bar{q}}\ell\overline{\nu}_\ell)$



corrected data and CR models

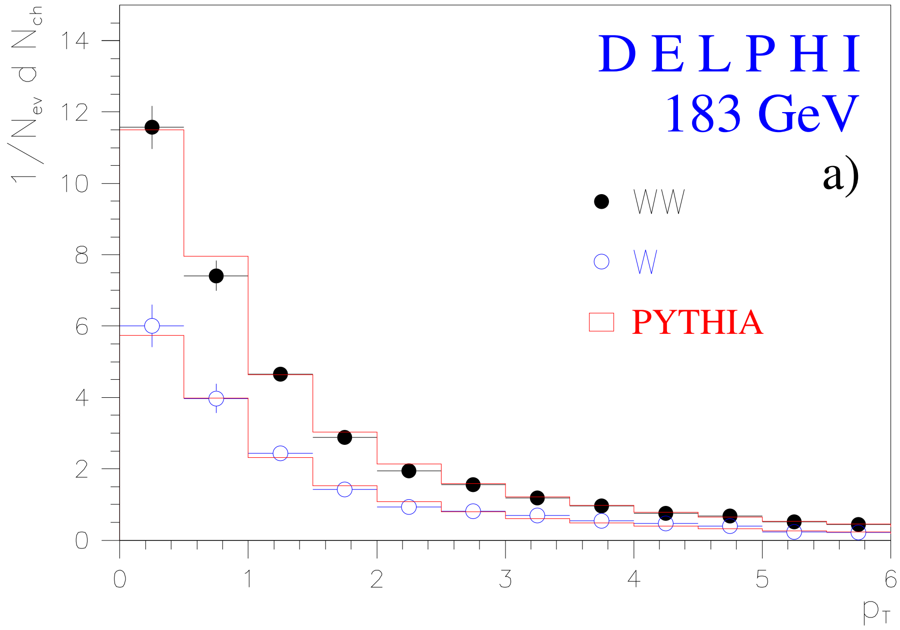
- Largest effect predicted by AR 3, still consistent with data
- O also measures:

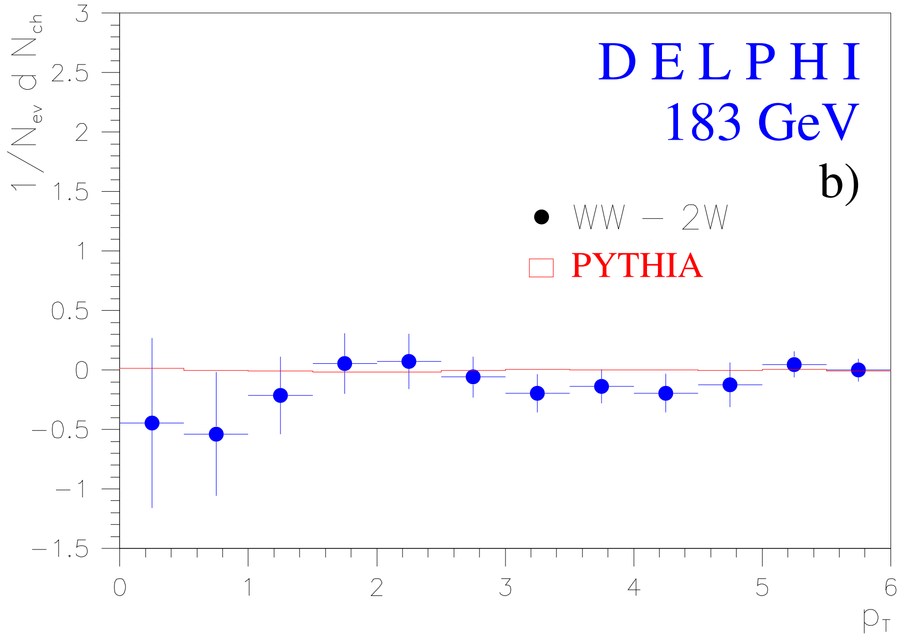
$$
\begin{aligned}
\langle x_p^{4\mathrm{q}} \rangle &= (3.16 \pm 0.05 \pm 0.04) \times 10^{-2} \\
\langle x_p^{\mathrm{q\bar{q}}\ell\overline{\nu}_\ell} \rangle &= (3.25 \pm 0.07 \pm 0.04) \times 10^{-2} \\
\Delta \langle x_p \rangle &= (-0.09 \pm 0.09 \pm 0.06) \times 10^{-2} \\
\langle (1-T)^{4\mathrm{q}} \rangle &= 0.240 \pm 0.015 \pm 0.009 \\
\langle |y^{4\mathrm{q}}| \rangle &= 1.017 \pm 0.016 \pm 0.016
\end{aligned}
$$

Alternative Observables

P_T distribution and difference

Infer ν from missing momentum for thrust calculation



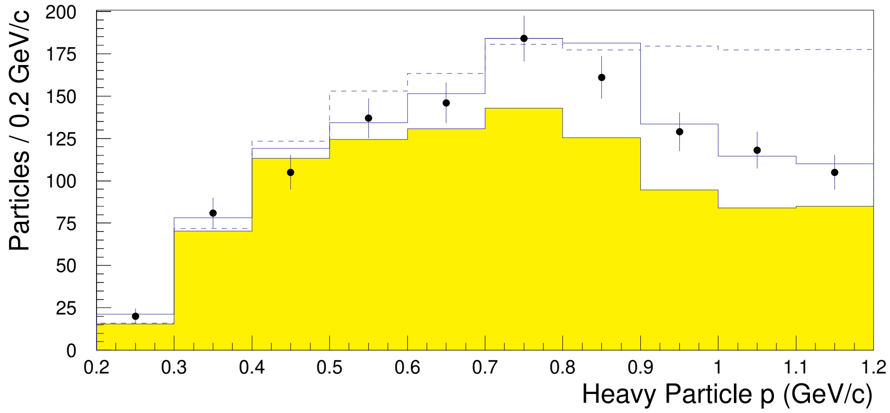


Effects of CR generally concentrated in soft particles

Recently predicted enhancement (SK) for heavy particles

CR in Heavy Hadrons (DELPHI)

- Heavy hadrons (K, p), low $P(0.2 - 1.2\ \mathrm{GeV})$
  $\Rightarrow$ 2-3$\times$ larger effect. More significant??
- TPC, RICH, VD for particle ID
- K, p tagging: Effic. $\sim$ 90–50%, Purity $=$ 90–75%



K,p observed

181 in $q\bar{q}q\bar{q}$

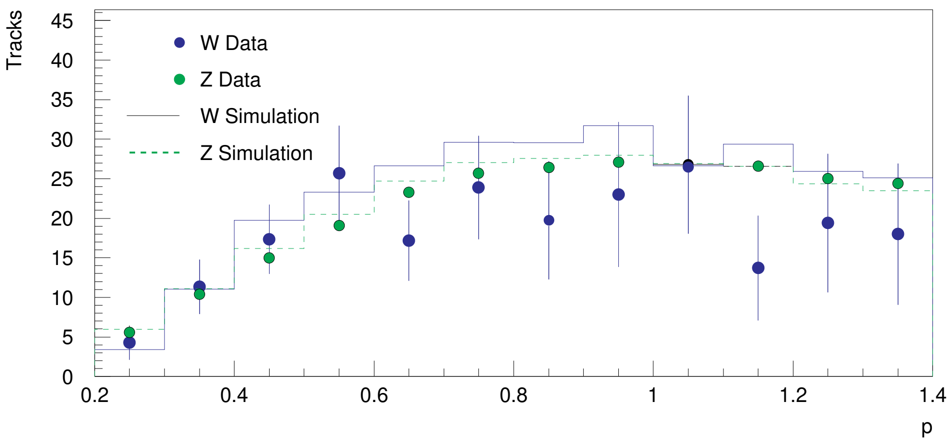
88 in $q\bar{q}\ell\bar{\nu}_\ell$

Unfolded for tagging effects, ratio heavy hadrons

$$(q\bar{q}q\bar{q})/(2q\bar{q}\ell\bar{\nu}_\ell) = 1.03 \pm 0.15 \text{ (stat.)}$$

Alternative, use Z^0 calibration data as reference

Pairs of Z^0, boosted $\Rightarrow$ emulate $W^+W^- \rightarrow q\bar{q}q\bar{q}$



systematics:

particle id $f(\theta)$

BG model

$$\text{Ratio } \langle n^{\text{heavy}} \rangle, \ \frac{W^+W^-}{Z^0Z^0} = 0.870 \pm 0.090 \pm 0.044$$

M_{W} Bias Estimates

Bias estimates (MeV) from models consistent with data

Expt.	A	D*	O
SK I	$+25 \pm 21^{\dagger}$	$+40 \pm 12$	$+50 \pm 17$
SK II	$+5 \pm 15$	–	$+17 \pm 17$
SK II′	$+17 \pm 15$	$+3 \pm 10$	$+18 \pm 17$
GH	–	$+13 \pm 18$	–
HW	-31 ± 25	–	
AR 2	–	–	$+73 \pm 18$
AR 3	–	–	$+146 \pm 18$

*Fast detector simulation   †Modified version of model

Note that

- A,O current version of M_{W} analyses
- D variant on main M_{W} analysis
- HERWIG and ARIADNE CR models tuned to Z^0 data

NB: significant statistical uncertainty on bias estimates

Summary

- CR studies maturing, MC tuning addressed

- $\Delta\langle n_{\rm ch}\rangle = \langle n_{\rm ch}^{\rm 4q}\rangle - 2\langle n_{\rm ch}^{\rm qq\ell\nu}\rangle$

  average $\Delta\langle n_{\rm ch}\rangle = +0.20 \pm 0.50({\rm stat.} + {\rm syst.})$

- Most models consistent with data

- Identified particle studies $\Rightarrow$ experimental challenge

- Current implementation of Ellis-Geiger model is not used for $M_{\rm W}$ bias estimates

- 1998 data should allow some models to be excluded

  $\Rightarrow$ better control of this as $M_{\rm W}$ systematic!