Pythia Tuning for LHCb

Kenneth Lessnoff

Kenneth.lessnoff@cern.ch

University of BRISTOL

Introduction

- Retune Pythia for the use of LHCb
- Requires the inclusion of excited B meson states.
  - Needed for same side tagging.
- These states are included by the tuning of PARJ variables in Pythia, which control the production of excited meson states.
- This leads to a significantly increased multiplicity as these parameters also control the production of light mesons.
- The multiplicity had been lowered by retuning the multiple interactions P_{Tmin} parameter, which controls the number of the multiple interactions which take place in parton parton collisions.
- This did not directly address the cause of the increased multiplicity.
- The retuning is a two part process.

University of BRISTOL

Introduction

- Retune the PARJ variables which control the spin of mesons.
- Keep the required fraction of excited B mesons.
  - Measured from LEP and Tevatron data
- Also ensure there is a fit to existing data for lighter mesons.
- Data from LEP used, as the clean environment allows good measurement of the production rates of different mesons which are affected by the PARJ variables.

Introduction

- After retuning to fit LEP data, it is necessary to retune to fit data from hadron hadron collisions.
- Specifically, CDF and UA5 data were used.
- Retuned old multiple interactions model in Pythia 6.3
- Multiplicity depends on a number of things:
  - Parton distribution function used.
  - Model of matter distribution in proton.
  - P_{Tmin}, a cut off in the transverse momentum transferred in parton parton interactions.
- It is this parameter which was tuned in the following work.

University of BRISTOL

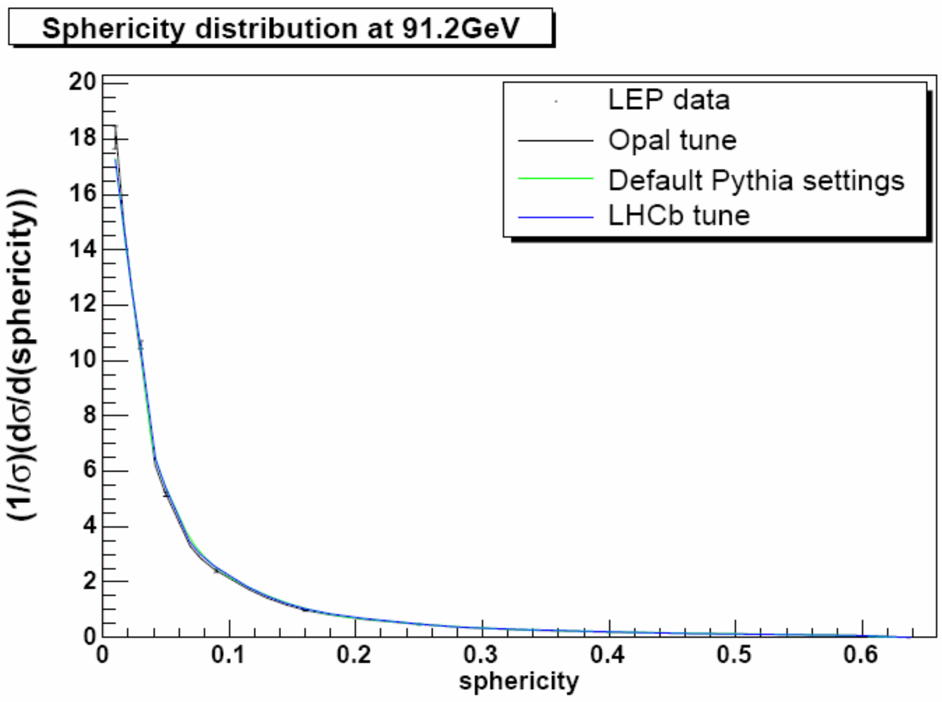
A look at e^-e^+ data.

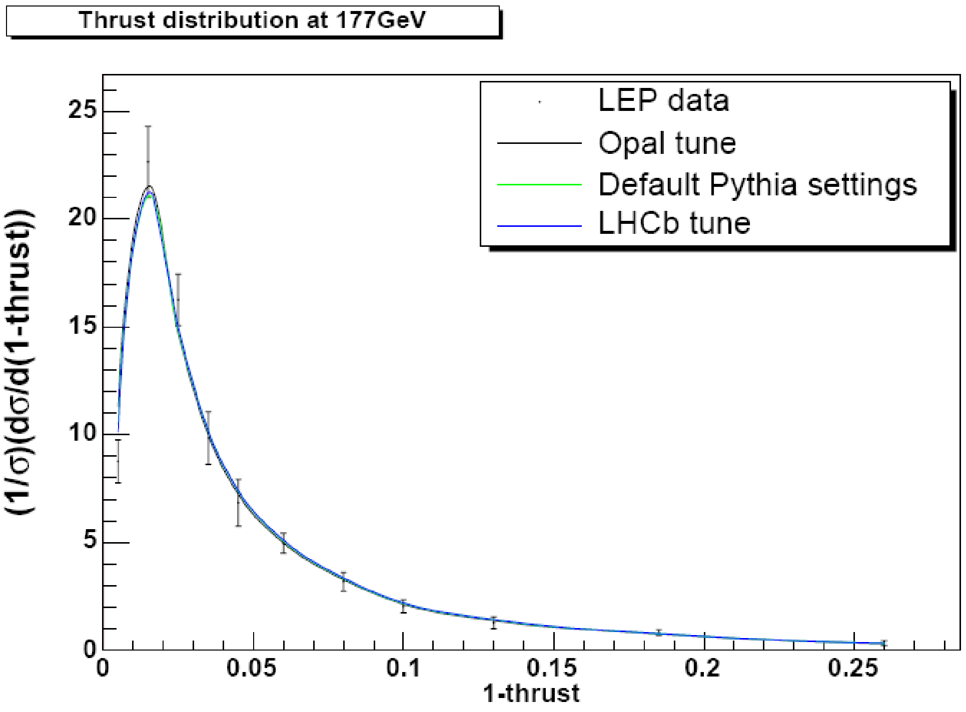
- Studies were made of the following:
  - Thrust and sphericity distributions
  - Charged multiplicity
  - Production rates of $\rho(770)^0$, $\omega(782)$, $\varphi(1020)$, $K^*(892)^{+/-}$ and $D^*(2010)^{+/-}$

University of BRISTOL

Thrust and Sphericity

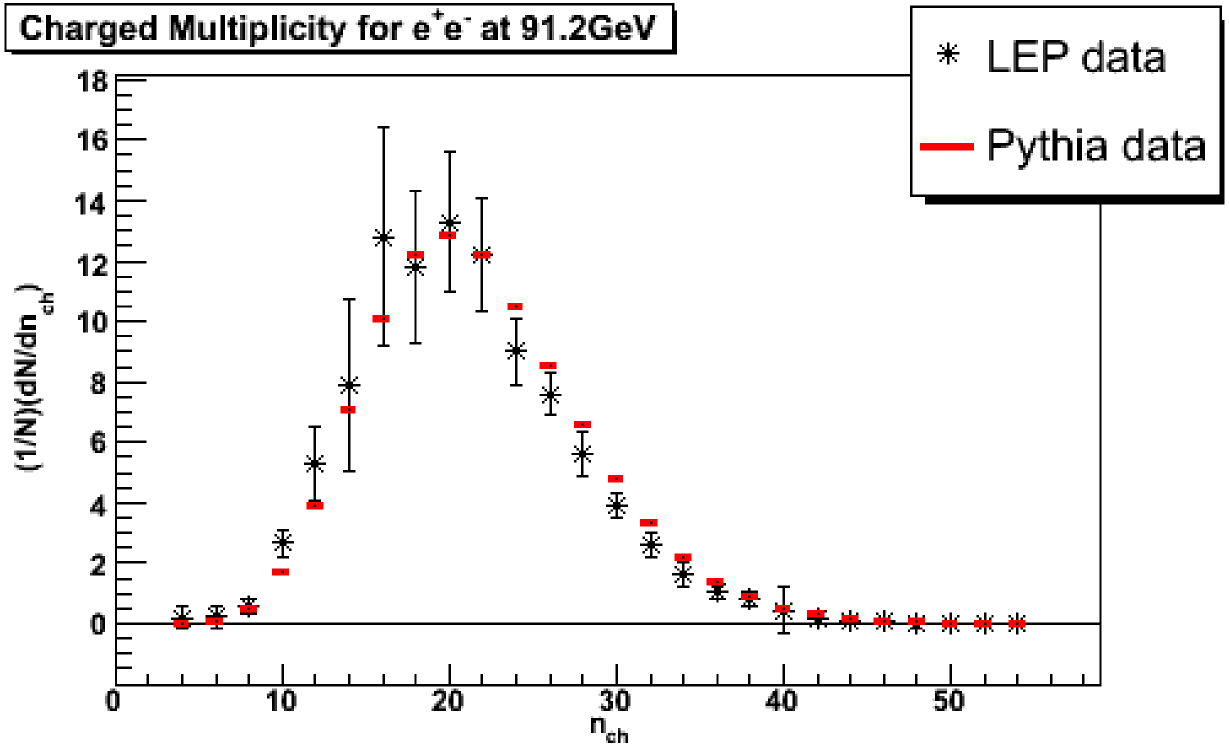
A good agreement with data found.





University of BRISTOL

Charged Multiplicity



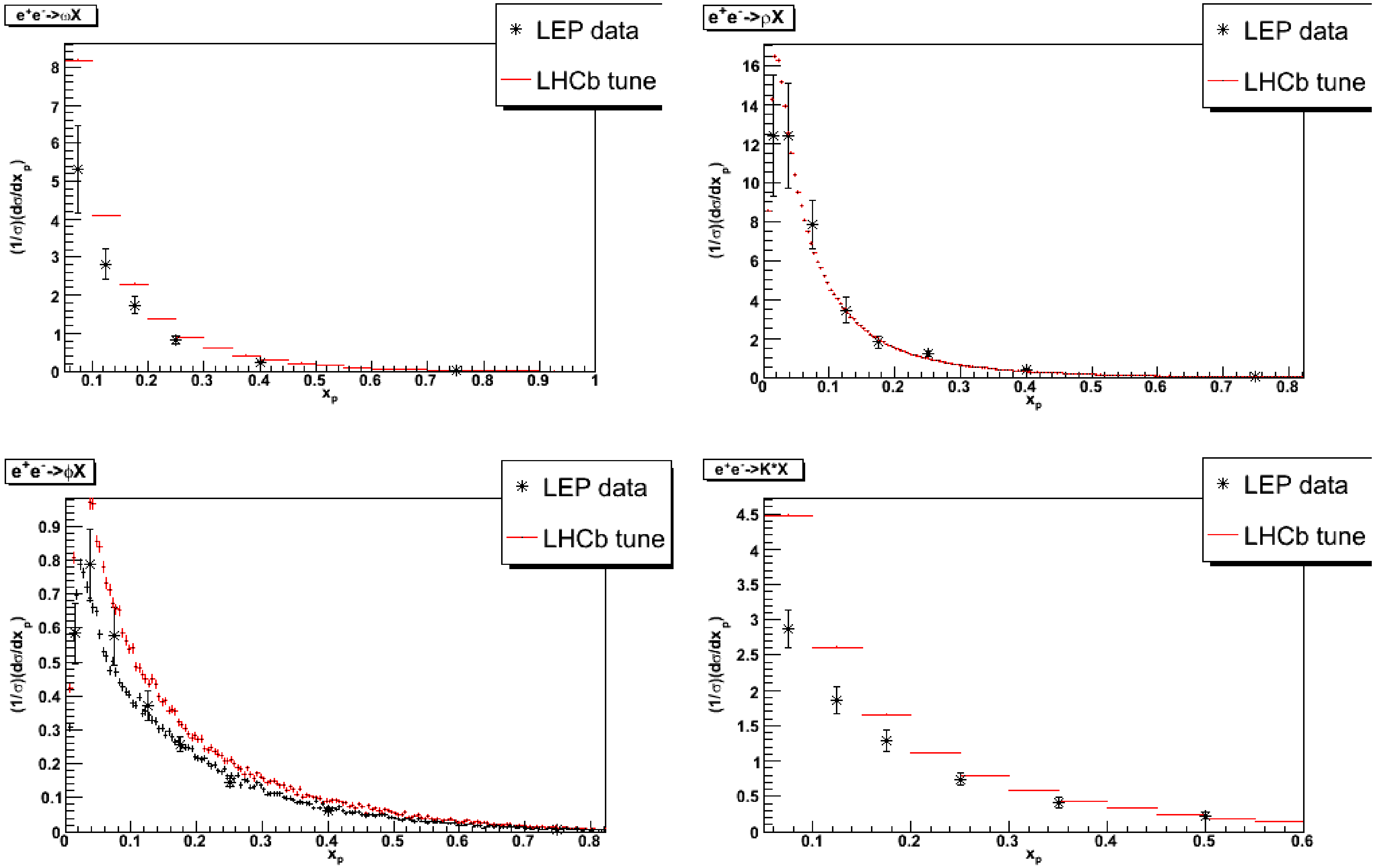
For LEP data

$<n_{ch}> = 20.9 \pm 1.2$

For Pythia data

$<n_{ch}> = 21.866 \pm 0.003$

A failure to reproduce production rates for specific particles with LHCb tune



- An improved fit was sought by tuning the following parameters:
  - PARJ(11) = probability a light meson has spin 1.
  - PARJ(12) = probability a strange mesons has spin 1.
  - PARJ(13) = probability a charmed or heavier meson has spin 1.

Parameter	Old Value	Trial Values
PARJ(11)	0.5	0 to 1
PARJ(12)	0.6	0 to 1

- More care is needed when tuning PARJ(13) as it affects the B-hadron fractions.

- The following are required:

Hadron Type	Fraction
B^0	40.5 %
B^+	40.5 %
B_s^0	9.9 %
b-Baryon	9.1 %

State	Fraction
B	21 %
B*	63 %
B**	16 %

- These depend on more than merely PARJ(13)
- Other adjustments are required

- The fractions depend on the following:
- PARJ(14) : Probability that a spin = 0 meson has orbital angular momentum 1, total spin = 1.
- PARJ(15) : Probability that a spin = 1 meson has orbital angular momentum 1, total spin = 0.
- PARJ(16) : Probability that a spin = 1 meson has orbital angular momentum 1, total spin = 1.
- PARJ(17) : Probability that a spin = 1 meson has

  orbital angular momentum 1, for a total spin = 2.

- P(B) = (1-p13)(1-p14) = 0.21
- P(B*) = p13(1-p15-p16-p17) = 0.63
- P(B**) = (1-p13) p14 + p13(p15+p16+p17) =0.16
- Trial changes from LHCb tune:

Parameter	Old Value	Trial Value(s)
PARJ(13)	0.75	0.67 to 0.79
PARJ(14)	0.162	1 – 0.21/(1-parj(13))
PARJ(15)	0.018	0.018
PARJ(16)	0.054	0.054
PARJ(17)	0.090	0.928 – 0.63/parj(13)

- PARJ(11) and PARJ(12) varied from 0 to 1 in steps of 0.1.
- PARJ(13) varied from 0.67 to 0.79 in steps of 0.01.
- Data produced with all combinations of each of these settings.
- The χ^2 values minimised with respect to the PARJ variables.
- 500000 Monte Carlo events generated for each combination of PARJ settings.
  - Experimental errors dominate those on Monte Carlo data.

University of BRISTOL

Reminder or relevant parameters

- PARJ(11) = probability a light meson has spin 1.
- PARJ(12) = probability a strange meson has spin 1.
- PARJ(13) = probability a charmed or heavier meson has spin 1
- PARJ(14) : Probability that a spin = 0 meson has orbital angular momentum 1, total spin = 1.
- PARJ(15) : Probability that a spin = 1 meson has orbital angular momentum 1, total spin = 0.
- PARJ(16) : Probability that a spin = 1 meson has orbital angular momentum 1, total spin = 1.
- PARJ(17) : Probability that a spin = 1 meson has orbital angular momentum 1, for a total spin = 2.

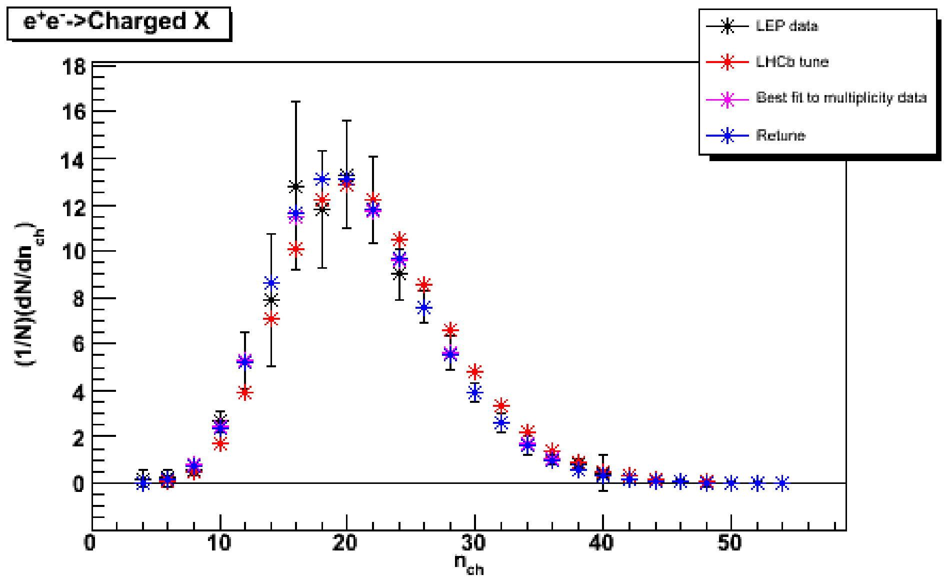
University of BRISTOL

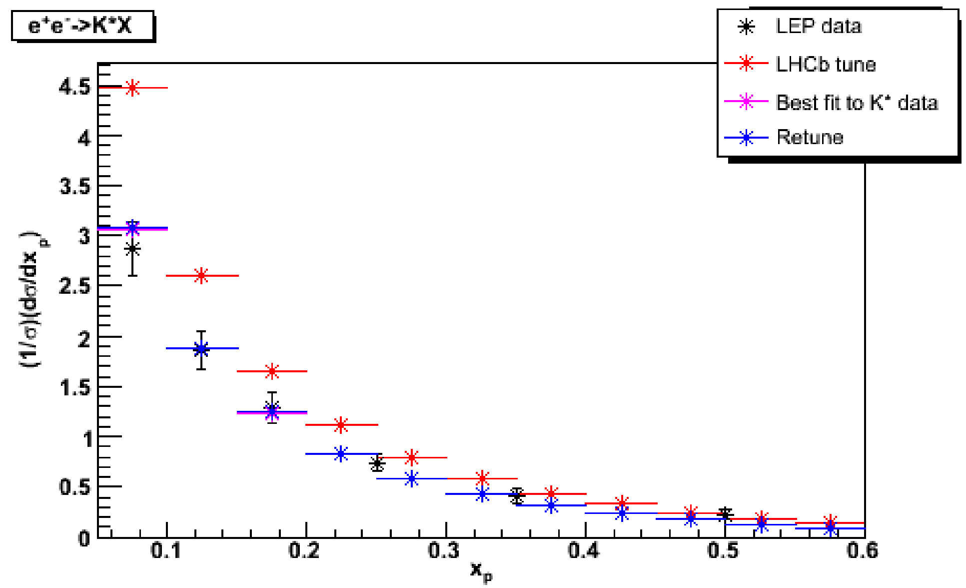
χ^2/n.d.f. values for different settings

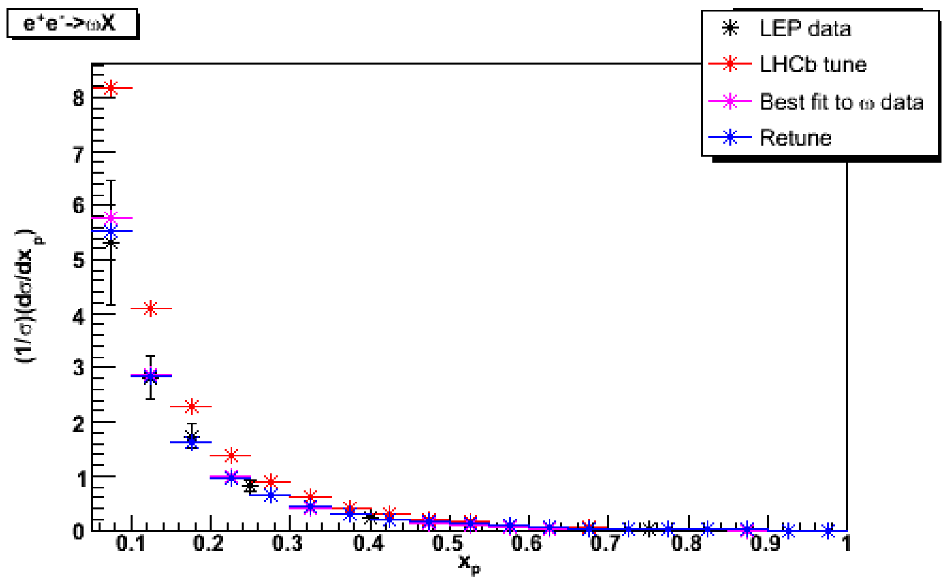
Tune / Data	LHCb	Parj(11)=0.7 Parj(12)=0.4 Parj(13)=0.78	Parj(11)=0.1 Parj(12)=0.2 Parj(13)=0.76	Parj(11)=0.9 Parj(12)=0.4 Parj(13)=0.75	Parj(11)=0.6 Parj(12)=0.3 Parj(13)=0.76	Parj(11)=1.0 Parj(12)=1.0 Parj(13)=0.79	Parj(11)=0.3 Parj(12)=0.8 Parj(13)=0.78	Parj(11)=0.5 Parj(12)=0.4 Parj(13)=0.79
K*	**9.70686**	**0.581911**	6.30127	0.700179	2.09931	55.3692	34.6064	**0.604811**
ω	**21.2486**	21.2159	**0.190781**	54.5138	24.3161	45.7763	1.53477	**3.03835**
φ	**5.59246**	1.0689	8.15106	**0.769361**	2.96809	44.4911	14.5653	**1.35154**
ρ	**2.16063**	1.2169	20.1401	4.75999	**1.05774**	5.82269	9.17321	**2.42266**
D*	**3.35683**	2.71016	3.51176	3.15332	3.1297	**2.04131**	2.79938	**2.62796**
N_{ch}	**1.11694**	0.806028	0.645477	2.87359	0.79549	5.41735	**0.142706**	**0.152342**
All	**43.1823**	27.5998	38.9404	66.7702	34.3664	158.918	62.8218	**10.1977**

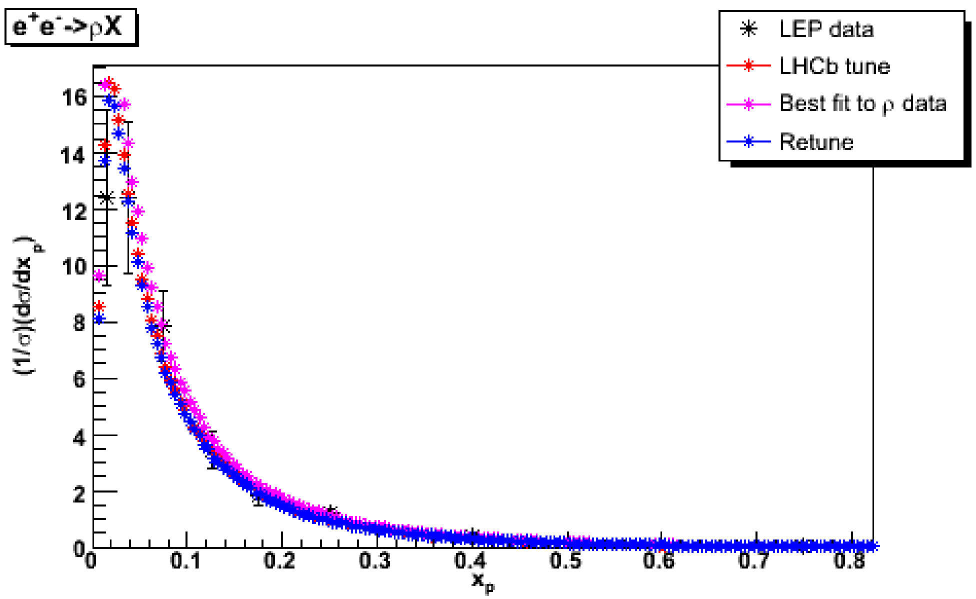
University of BRISTOL

Improvements in the Monte Carlo Data









Changes to the tuning

Parameter	Old value	New Value
PARJ(11)	0.5	0.5
PARJ(12)	0.6	0.4
PARJ(13)	0.75	0.79
PARJ(14)	0.162	0
PARJ(17)	0.09	0.131

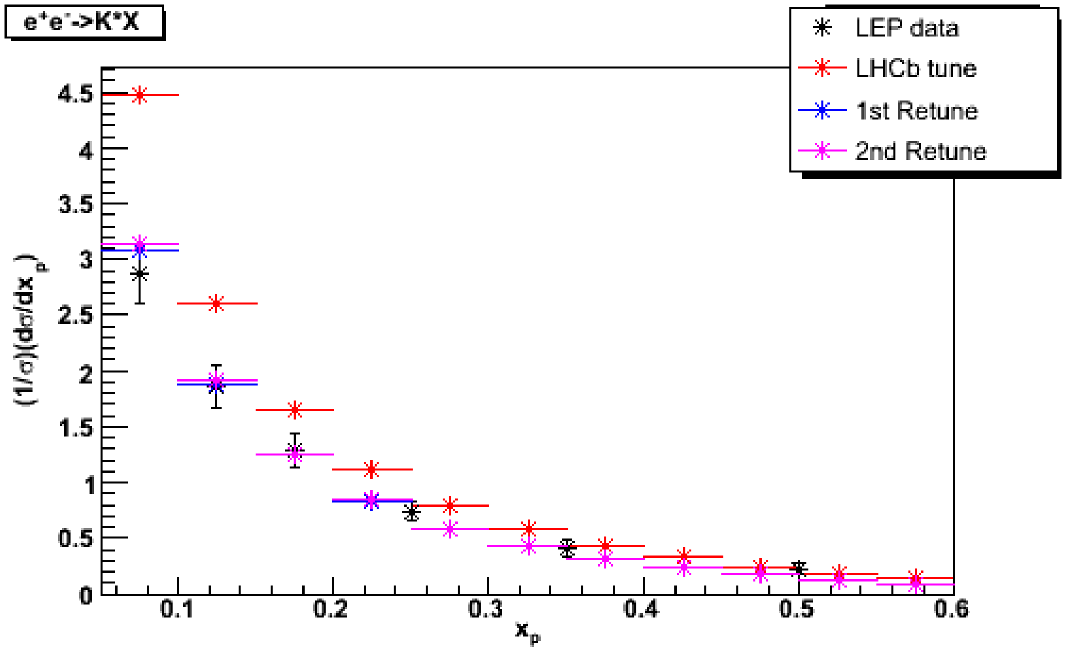
Value of PARJ(14) is unphysical. Cannot produce spin 0 mesons with orbital angular momentum 1.

University of BRISTOL

A second retuning of PARJ variables

- A second retuning process was undertaken to get round problem with PARJ(14).
- PARJ(11) and PARJ(12) varied as before.
- PARJ(14) fixed at its DELPHI tune value of 0.09
  - Implies PARJ(13) = 0.769
- To keep desired excited B fractions then requires a fixed value for PARJ(15) + PARJ(16) + PARJ(17)
- PARJ(15) kept at LHCB tune value of 0.018
- Requires PARJ(16) + PARJ(17) = 0.163
  - Varied PARJ(16) in steps of 0.0163

- Similar improvements seen in this as the last retuning.



- However this tuning process suffers from a problem similar to the last. The best fit is found with PARJ(16)=0 Cannot produce spin 1 mesons with orbital angular momentum 1, total spin 1.

University of BRISTOL

Remarks on PARJ tuning.

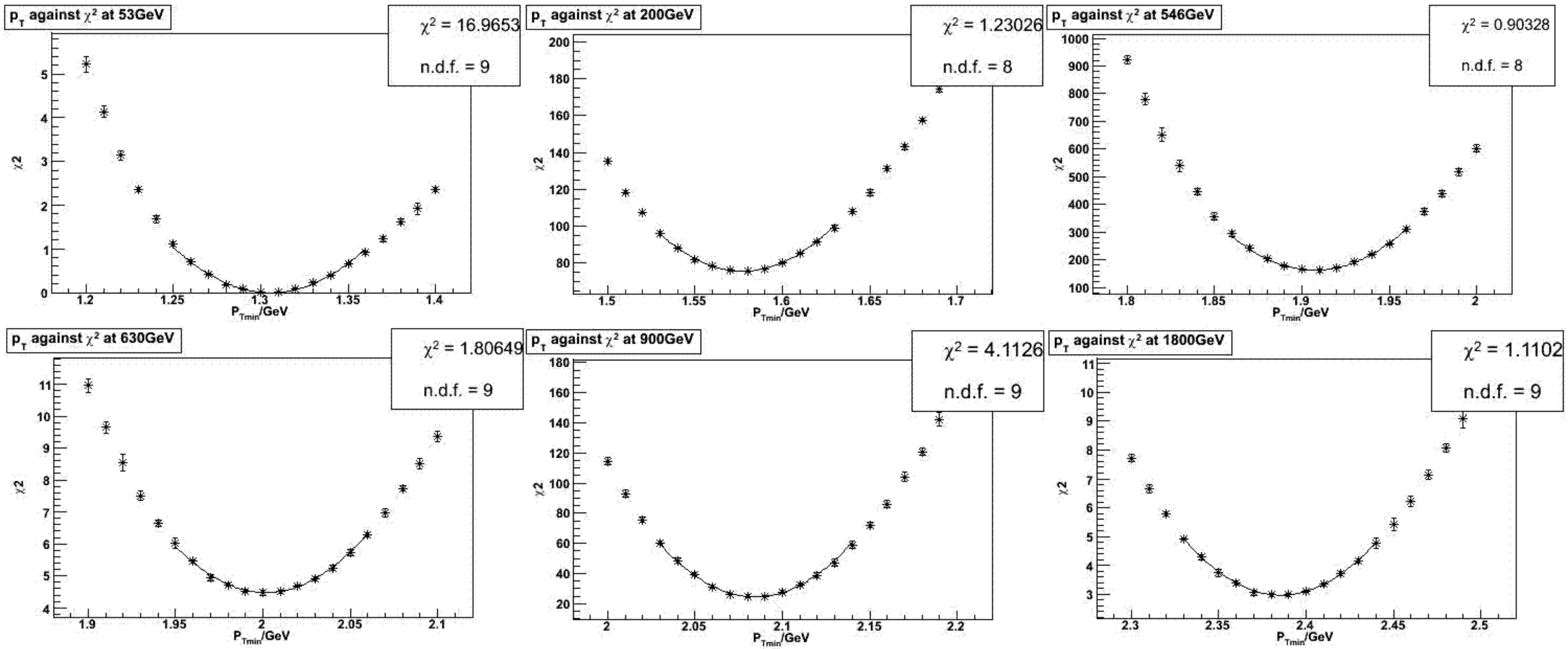
- The current state of affairs in not wholly satisfactory due to the zero value of one or other PARJ variables.
- A solution to this problem might be found in a number of ways.
  - Use data on other mesons in the tuning. Data on mean production rates exists in many cases.
  - Do not fix any of the PARJ variables. This would require the generation of much more data.
  - Modify Pythia so that including excited B mesons does not also necessitate the inclusion of excited light mesons.
- These methods are not undertaken here.
  - Despite problems, a significant improvement is seen in comparison to the LHCb tune.

Proton anti-proton collisions.

- After retuning the PARJ variables, a retuning of the parton-parton interaction parameters was required to bring the multiplicity of p-pbar events back up.
- The tuning was done using the same multiple parton-parton interaction model as the existing tune had used.
- The parameter which was tuned was the P_{Tmin} parameter.
- This represents a cut-off in the transverse momentum transferred in the interaction.
- This controls the number of parton-parton interactions and as a result the overall multiplicity of the event.

Tuning of P_{Tmin}

- The data being considered is from CDF and UA5
  - Pseudorapidity distributions at 200, 546, 630, 900 and 1800 GeV for non single diffractive events.
  - $<dN_{ch}/d\eta>|_{\eta<0.25}$ at 53GeV.
- This time only one parameter, PARP(82) is changed.
- Again it is changed in small steps and the χ^2 between experimental and Monte Carlo data found.
- For each P_{Tmin} value, at each energy, 5 sets of MC data generated.
- Quadratic function fitted through the points.



- P_{Tmin} found from minimising function.
- Error found from change needed to χ^2 increase by one.

New values of P_{Tmin}

Energy/GeV	Old P_{Tmin}/GeV/c	New P_{Tmin}/GeV/c
53	1.40±0.06	1.31±0.05
200	1.72±0.04	1.58±0.01
546	2.02±0.02	1.907±0.004
630	2.05±0.07	2.00±0.04
900	2.16±0.03	2.085±0.009
1800	2.49±0.08	2.39±0.04

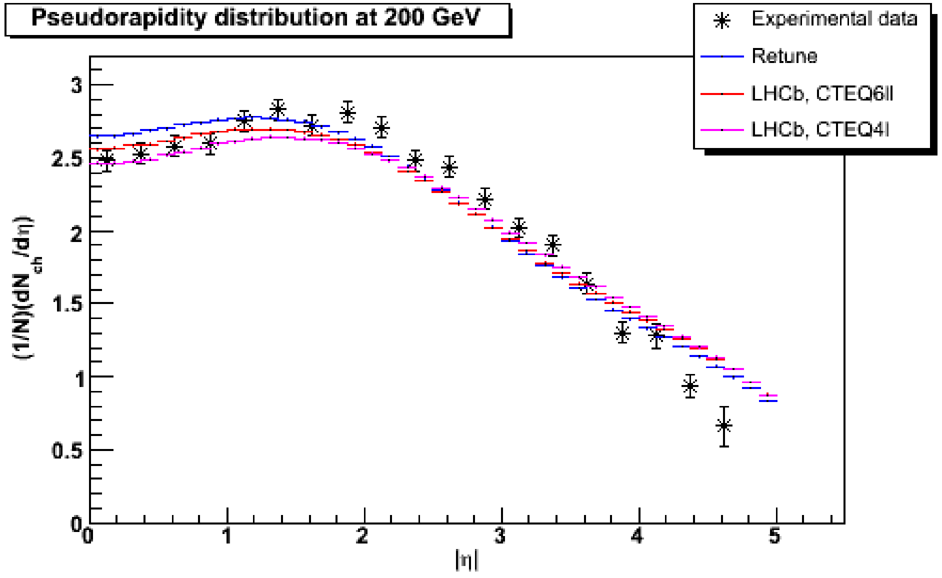
χ^2 values for different settings

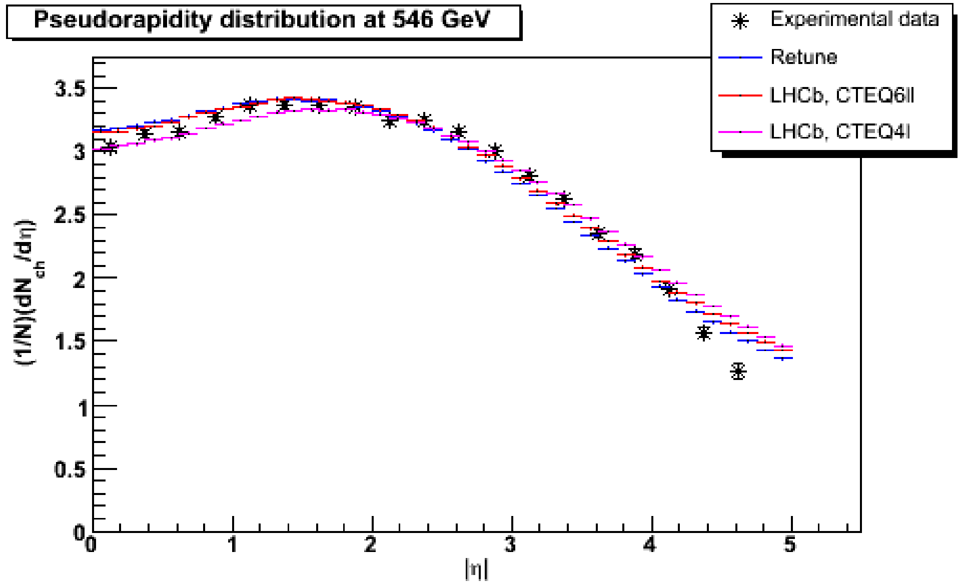
- The data produced is broadly similar to before.
- At some energies the χ^2 value is better, at others worse:

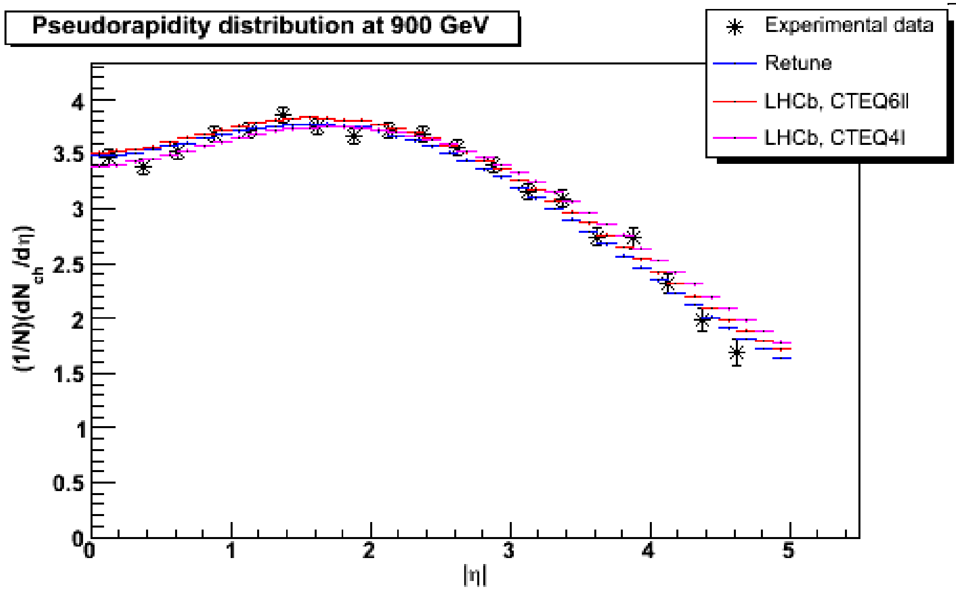
Tune / Energy/GeV	Default with CTEQ6ll	Default with CTEQ4l	Retune with CTEQ6ll
53	0.067	0.0003	0.003±0.002
200	80.9	80.2	75.6±0.4
546	153.4	140.2	160.6±2.5
630	2.94	5.50	4.47±0.08
900	35.4	27.7	24.8±0.7
1800	2.13	5.77	2.98±0.05
	274.8	259.4	268.5 ±2.5

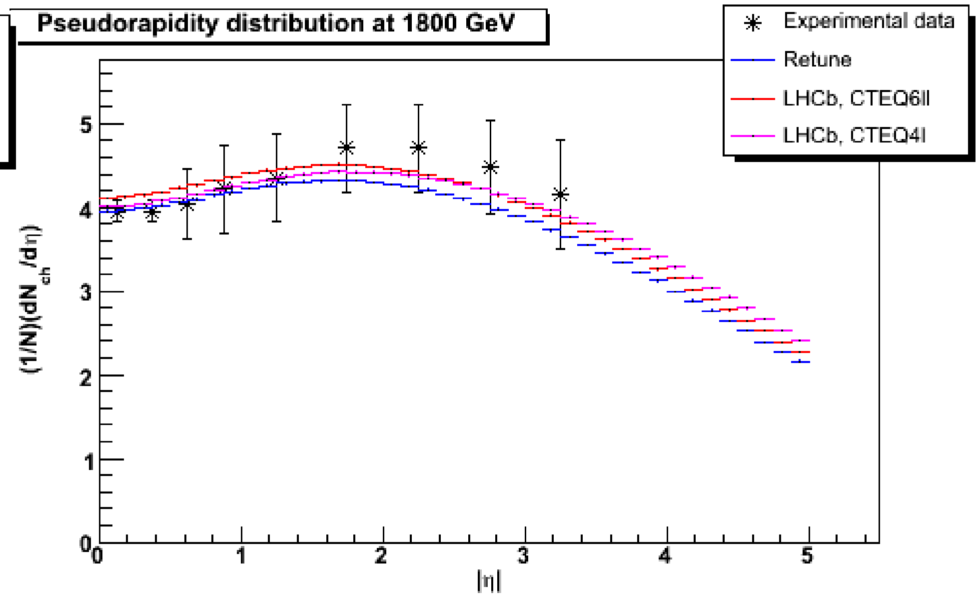
University of BRISTOL

Reproduction of experimental data



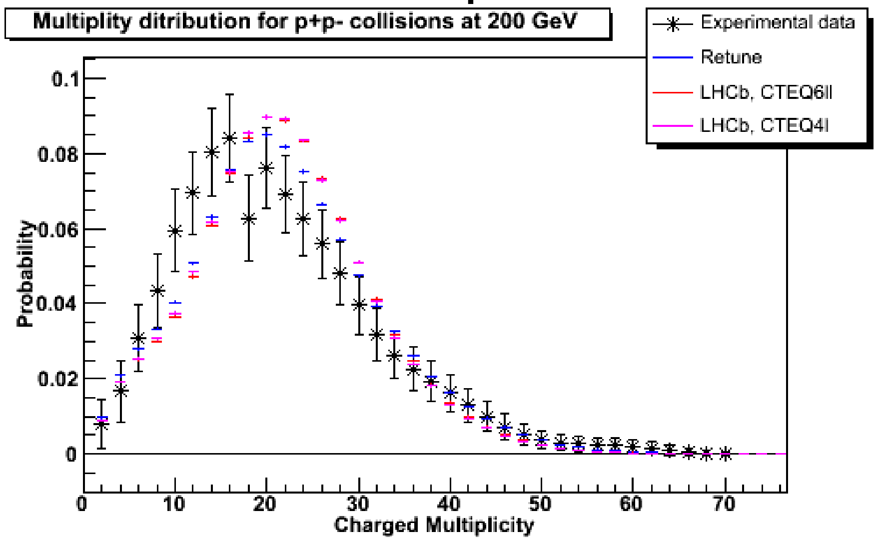


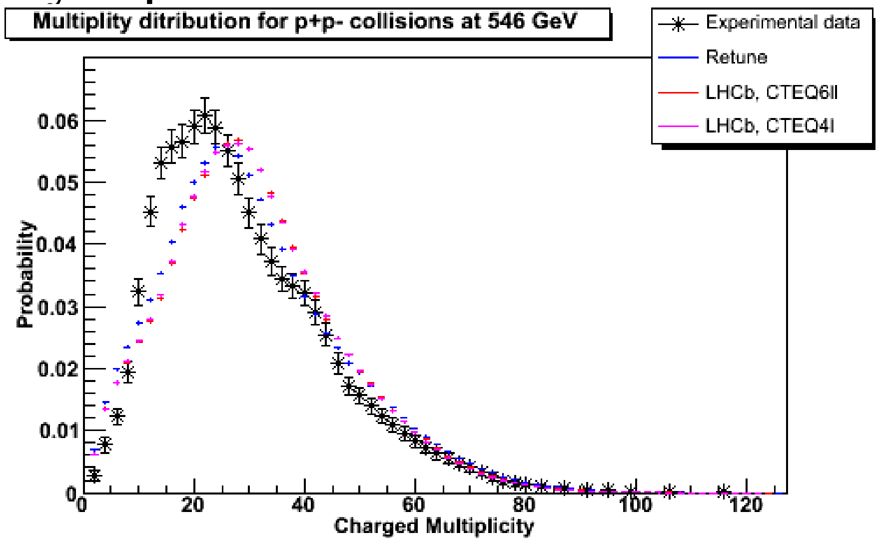


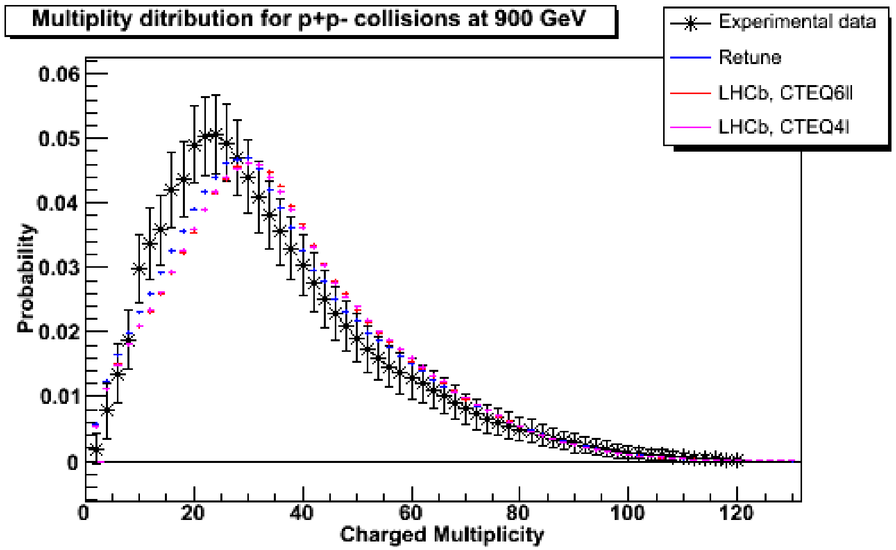


Reproduction of experimental data

- Small improvement in multiplicity reproduction.





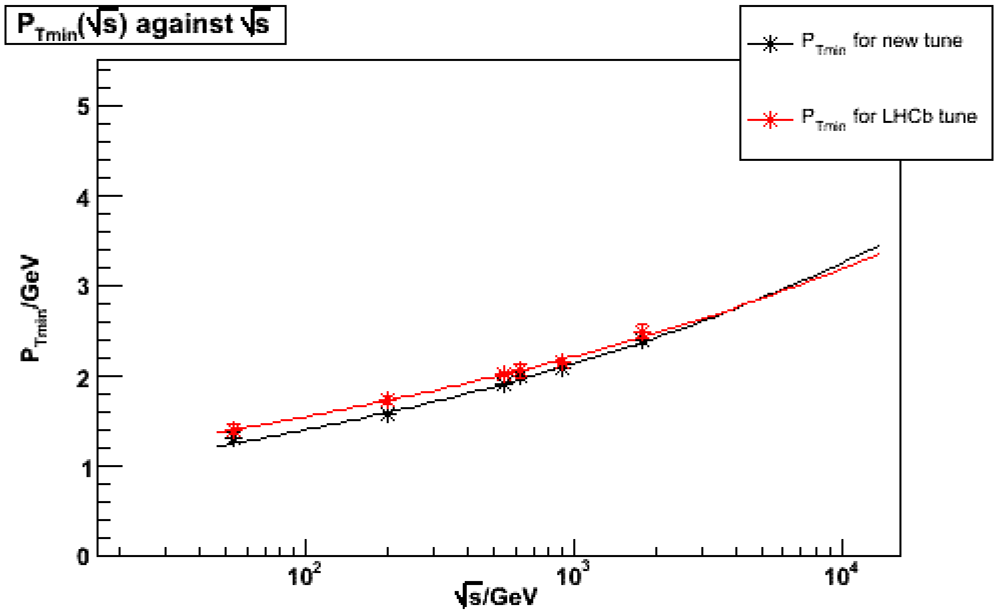


University of BRISTOL

Energy dependence of P_{Tmin}

- In Pythia the energy dependence of P_{Tmin} is given by
  $P_{Tmin}(s^{1/2}) = PARP(82).(s^{1/2}/PARP(89))^{PARP(90)}$
- Previously had PARP(90) = 0, to tune at a given energy.
- Now want to find the energy dependence

Variable	Old value	New value
PARP(82)	3.41GeV	3.45GeV
PARP(89)	14TeV	14TeV
PARP(90)	0.16	0.183

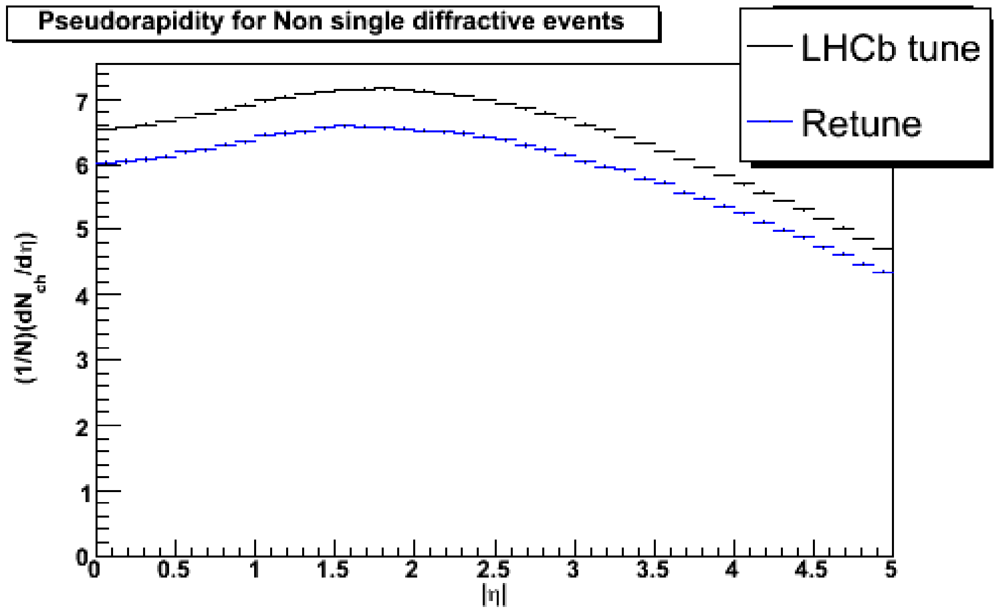


University of BRISTOL

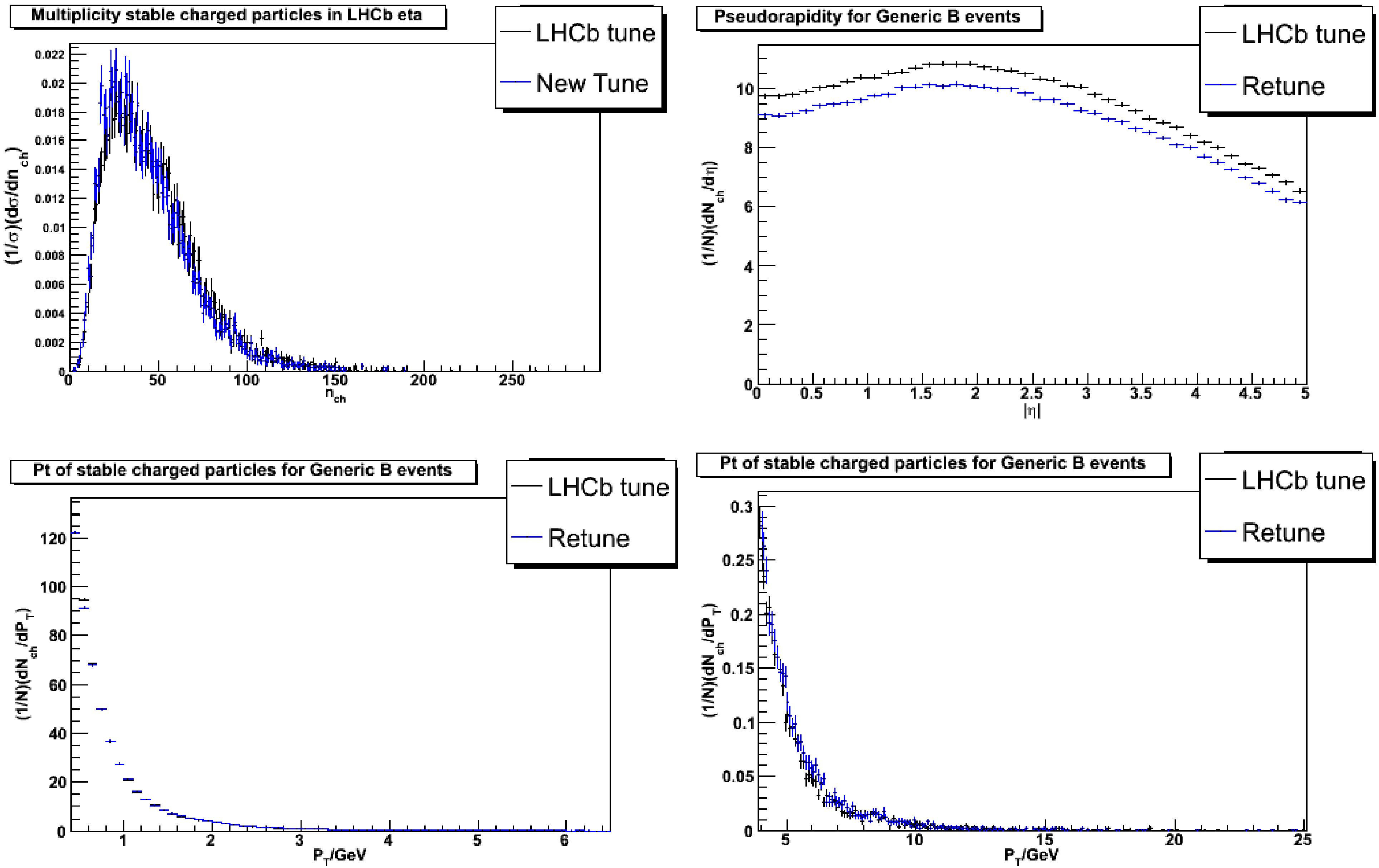
Comparison of LHCb tune and retune at LHC energy

- Energy dependence of $<dN_{ch}/d\eta>|_{\eta<0.25}$ phenomenologically well described by
  - $<dN_{ch}/d\eta>|_{\eta<0.25} = A.\ln^2(s) + B.\ln(s) + C$
  - Implies for LHC $<dN_{ch}/d\eta>|_{\eta<0.25} = 6.27 \pm 0.50$

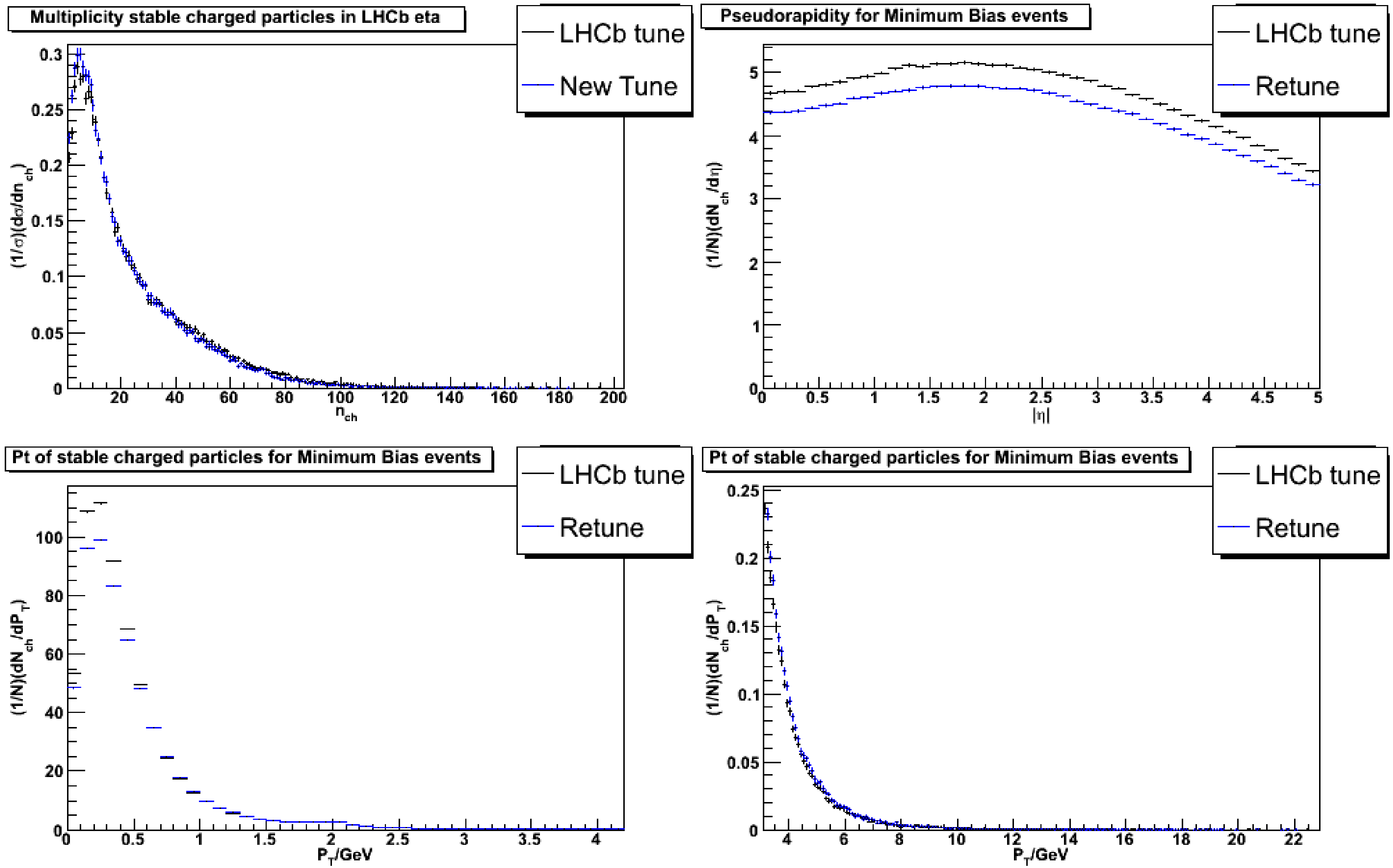
- Retuning gives a lower multiplicity, but $<dN_{ch}/d\eta>|_{\eta<0.25}$ is still within the errors of the predicted value.



A comparison of generic B events



A comparison of minimum bias events



Summary and Conclusions

- A substantial improvement in the fit to LEP data can be achieved by changing the value of PARJ variables to:
  - PARJ(11) = 0.5, PARJ(12) = 0.4, PARJ(13) = 0.79, PARJ(14) = 0 PARJ(15) = 0.018, PARJ(16) = 0.054, PARJ(17) = 0.131
- This requires certain changes in the setting which control parton parton interactions:
  - PARP(82) = 3.45, PARJ(90) = 0.183
- This cause a small decrease in the multiplicity predicted for the LHC. The lower multiplicity is still within the errors of prediction based upon data from lower energies.