Modelling of low transverse momentum in hadronic interactions

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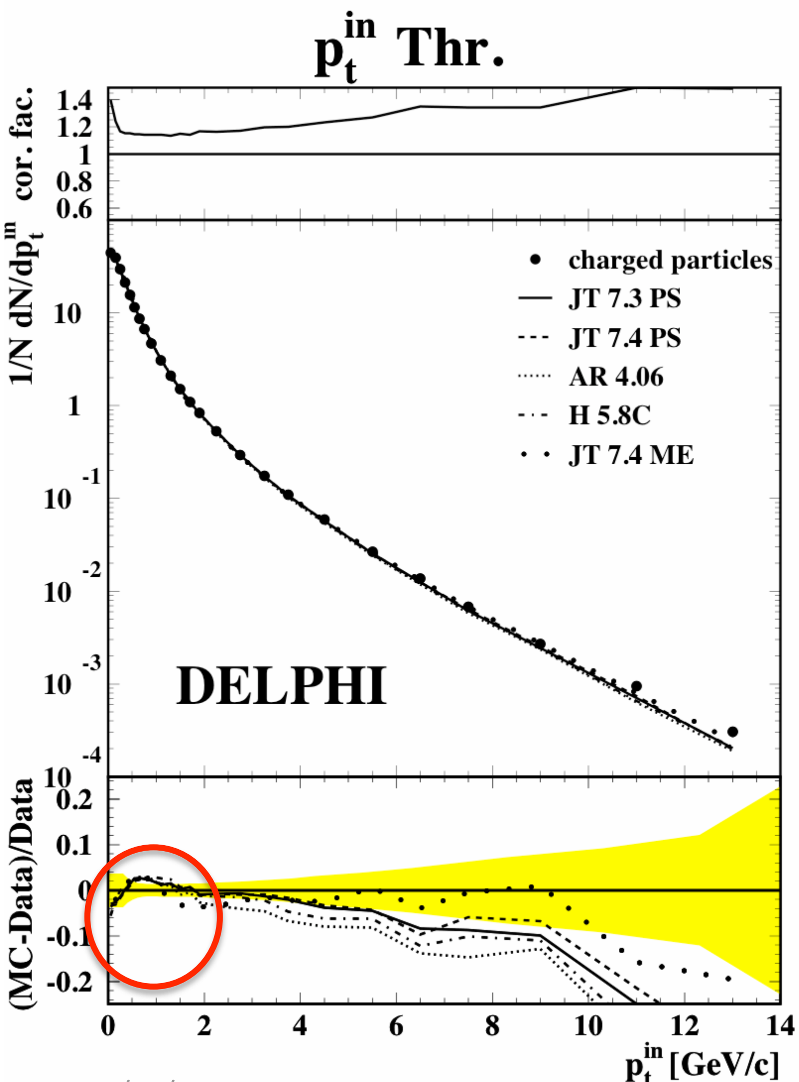
- ***motivation : characteristic data/MC discrepancies observed in LEP->LHC data***
- ***low pT region (< 1 GeV) dominated by 'intrinsic' hadron pT (acquired in the fragmentation process)***
- ***alternative models of fragmentation of the Lund string***
- ***observables & model tuning***

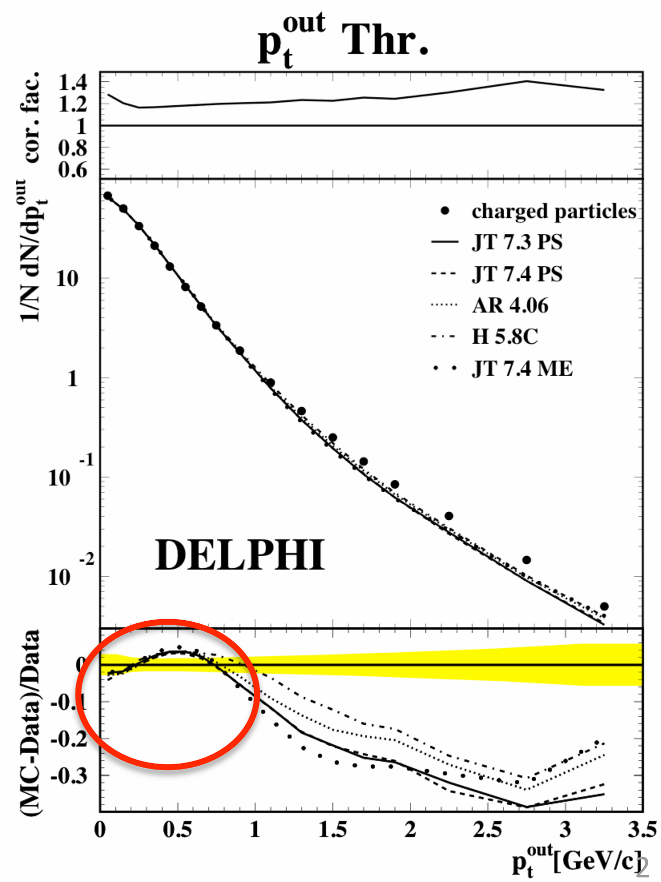
Intrinsic charged particle pT in LEP data

Z.Phys.C73,11(1996)

Characteristic 'bump' around pT~0.5 GeV/c
-> fragmentation

Tails not well described -> parton shower



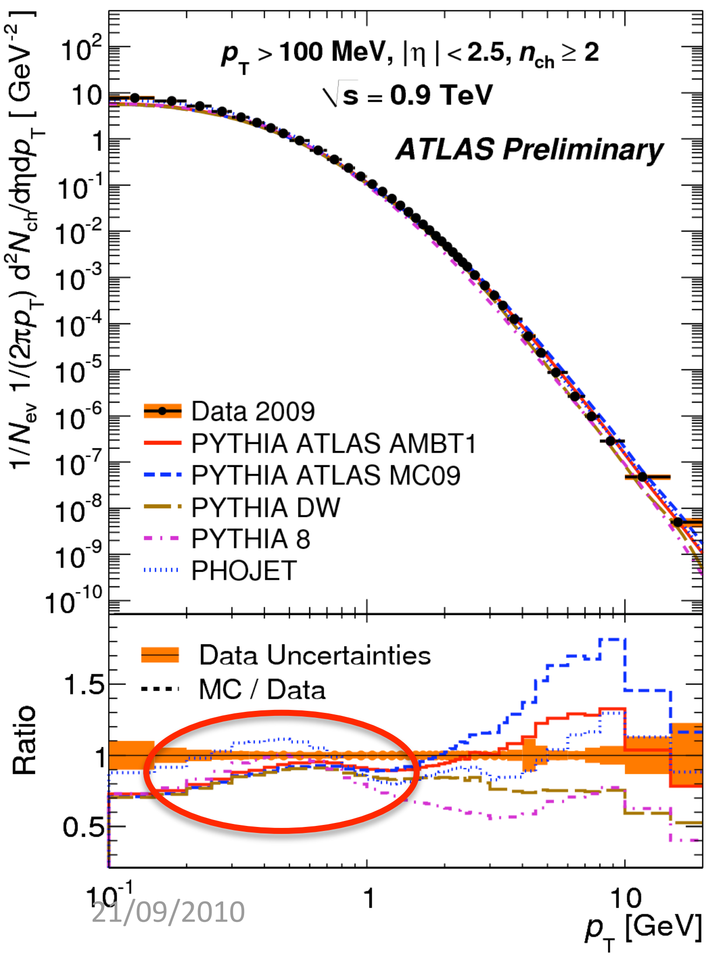


Intrinsic charged particle pT in LHC data

ATLAS-CONF-2010-046

complex picture : diffractive physics, multiple interactions, proton structure

technically demanding : low pT tracking, not trivial



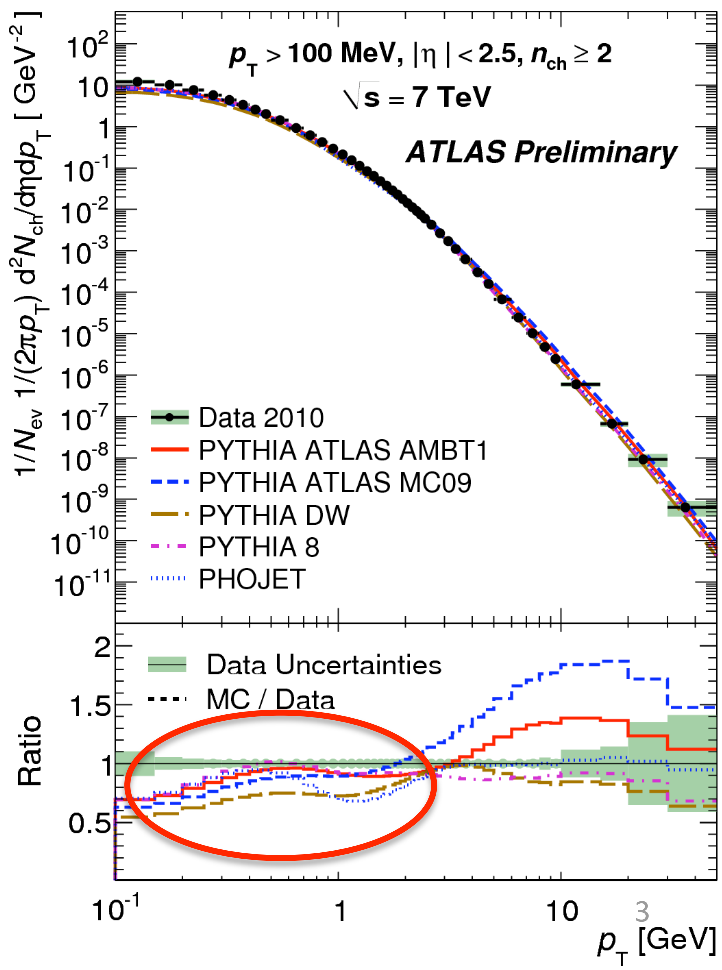
low pT 'bump'

much like

the one

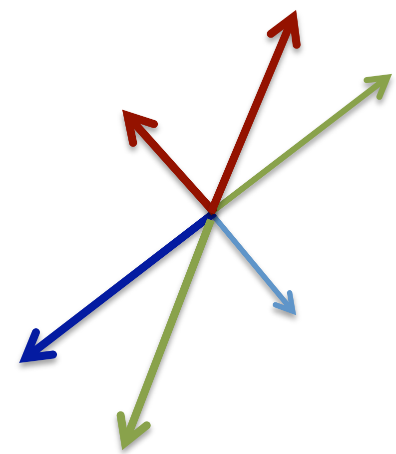
known

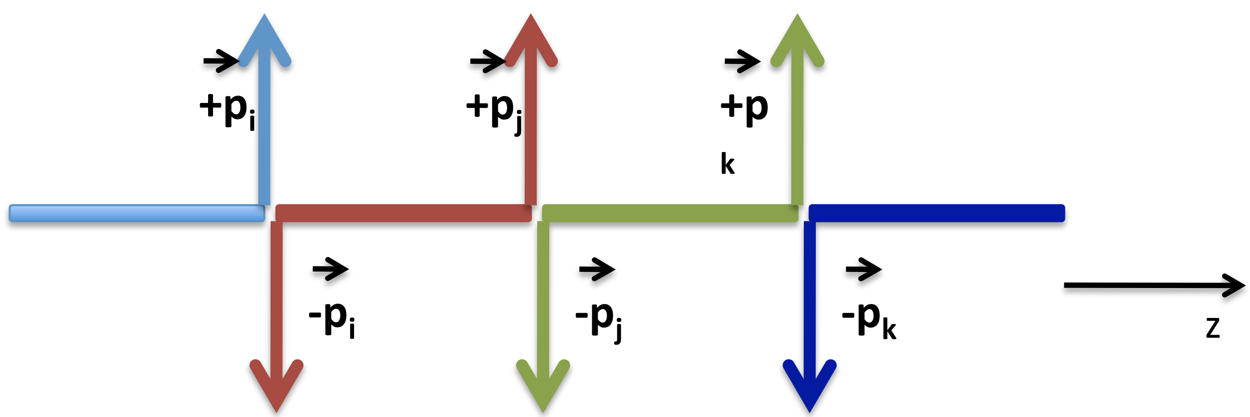
from LEP data



Transverse momentum generation in Lund string fragmentation

- ***Standard Lund model : tunneling effect (at every breaking point, newly created quark/antiquark is assigned $+p_t/-p_t$:***
  - ***-> size sampled from gaussian***
  - ***-> azimuthal direction random***





Alternative model

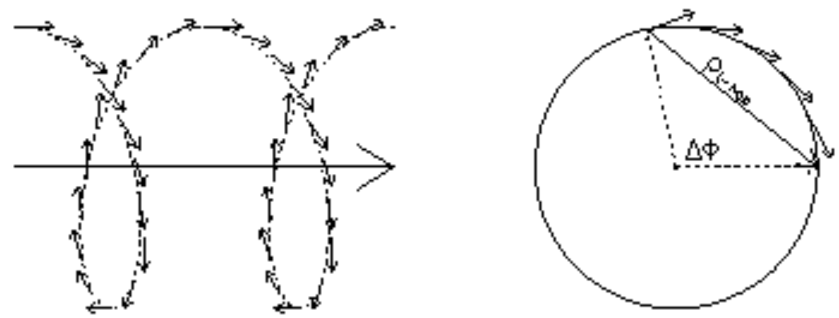
JHEP09(1998)014 , B.Anderson et al: "Is there a screwiness at the end of hadronic cascade?"

-> optimal packing of soft gluons at the end of parton cascade HELIX-LIKE

Hadron gets its transverse momentum by integration over momenta of soft gluons forming the corresponding string piece:

$p_T = 2\, r\, |\sin(0.5\, \Delta\phi)|$

r [GeV/c] , Δϕ difference of helix phase



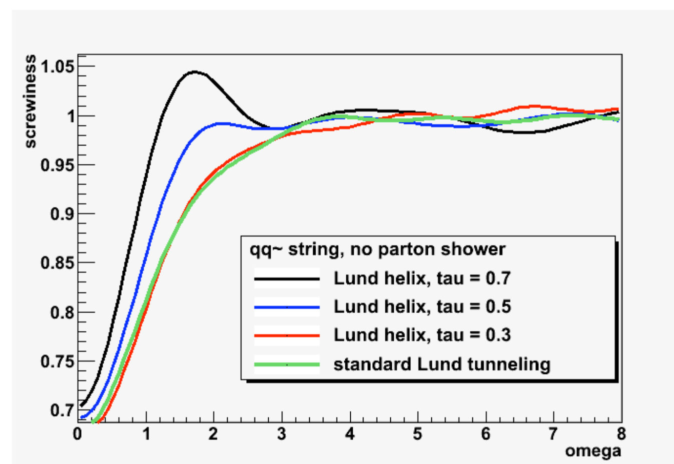
An observable proposed :

$$\textbf{screwiness}\ \ S(\omega) = \Sigma_{ev} P_{ev}\ |\Sigma_i \exp(i(\omega y_i - \phi_i))|^2$$

y rapidity of hadron

ϕ azimuthal angle of hadron

ω parameter

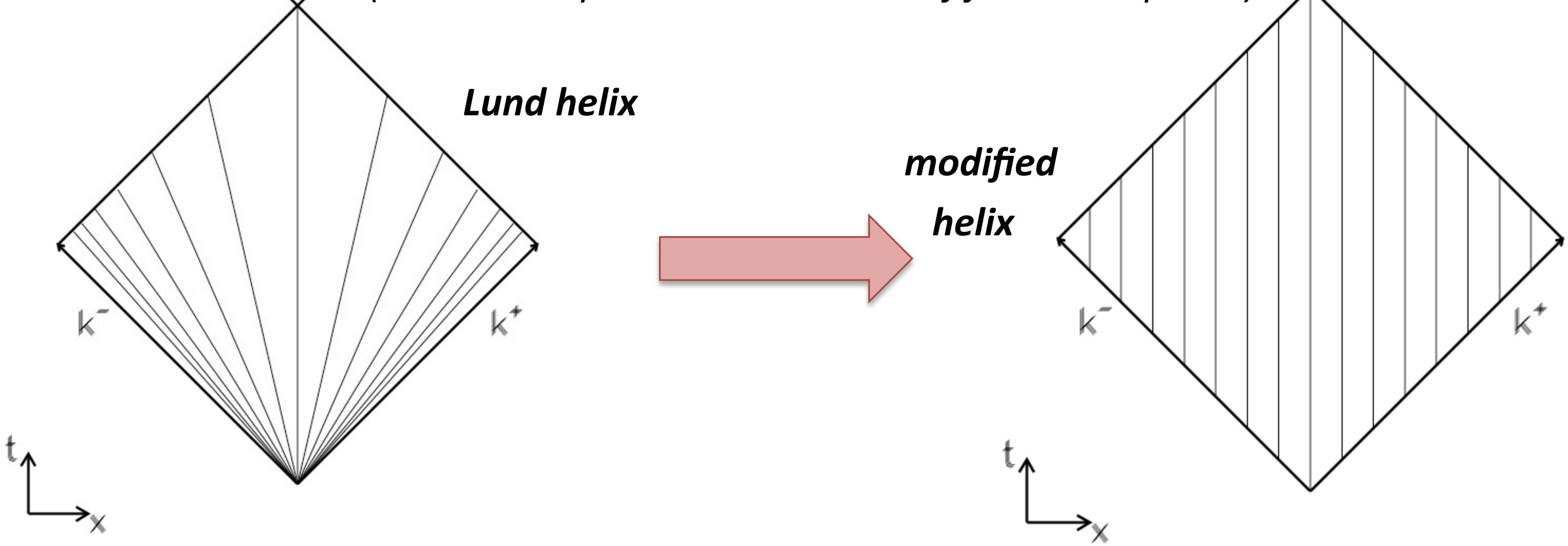


The model was immediately tested (DELPHI 98-156 PHYS 799), no signal found (τ ≤ 0.3)

Proposal: modification of the helix-string model

Helix-like string maintained, but parametrized differently:

(lines show space-time evolution of fixed helix phase)



$$\Delta\Phi = \Delta y/\tau$$
$$= 0.5/\tau \ln (k_i^+ k_j^- / k_i^- k_j^+)$$

$$\Delta\Phi = 0.5\, S \,| k_i^+ + k_j^- - k_i^+ - k_j^+ |\, M$$
$$= 0.5\, S\, \kappa\, \Delta l$$

M ... mass of the string

κ ... string tension

Proposal: modification of the helix-string model

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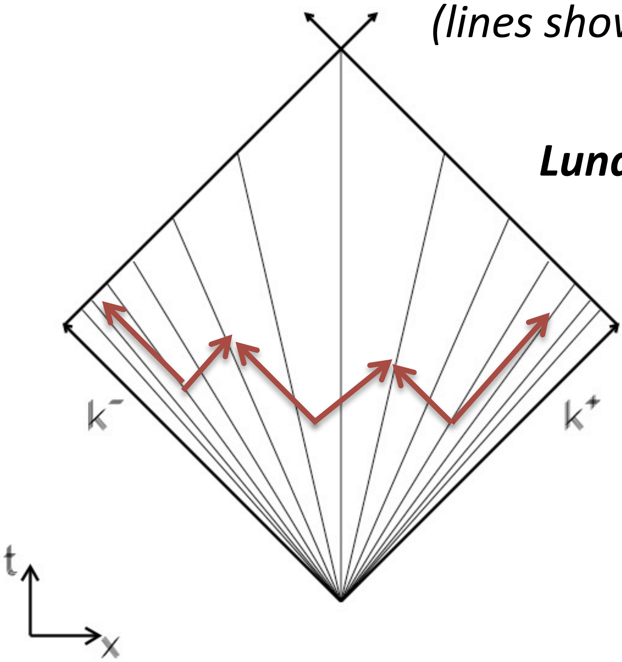
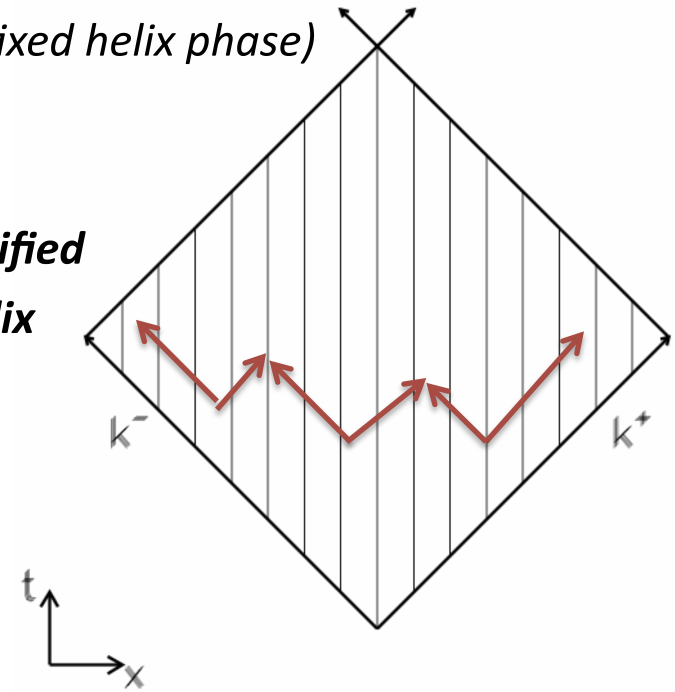


Lund helix

modified helix



$$\Delta\Phi = \Delta y/\tau$$
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$$\Delta\Phi = 0.5\ S\,|k_i^+ + k_j^- - k_i^+ - k_j^+|\,M$$
$$= 0.5\ S\ \kappa\ \Delta l$$

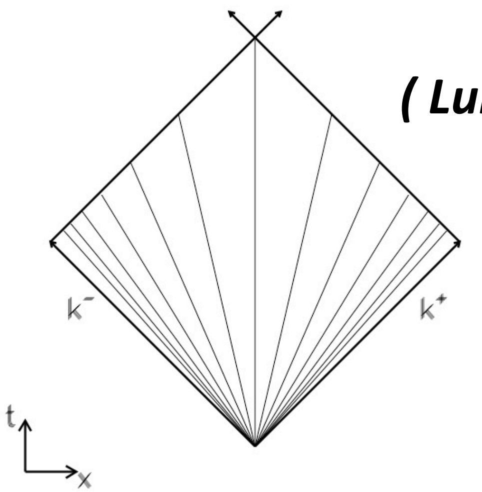
BOTH VARIANTS REMOVE THE AZIMUTHAL DEGREE OF FREEDOM

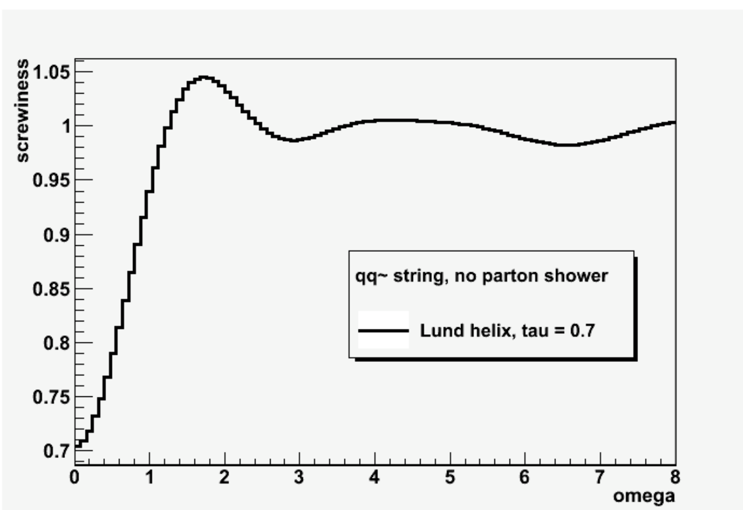
helix phase fixed by parametrization

Helix parametrization introduces correlations

azimuthal direction – rapidity

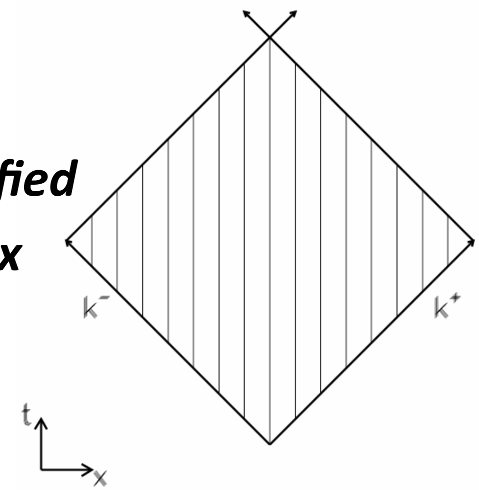
(Lund helix)

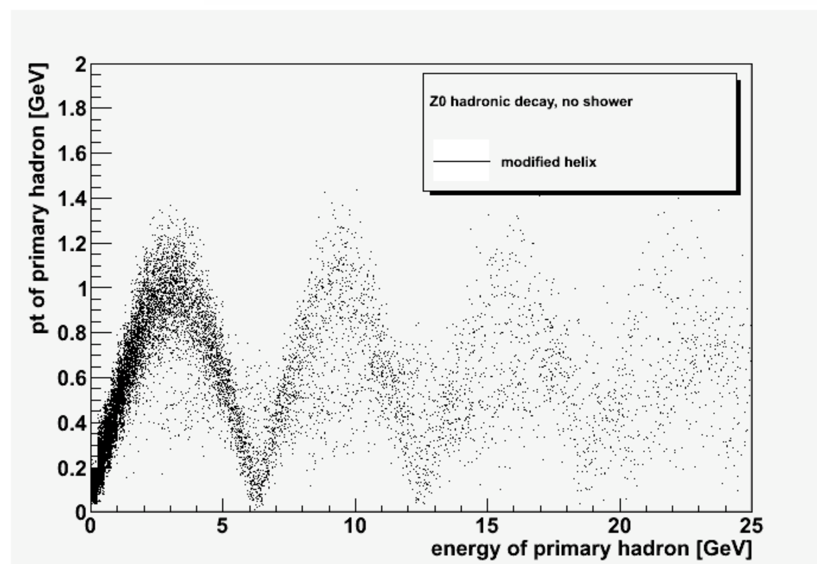




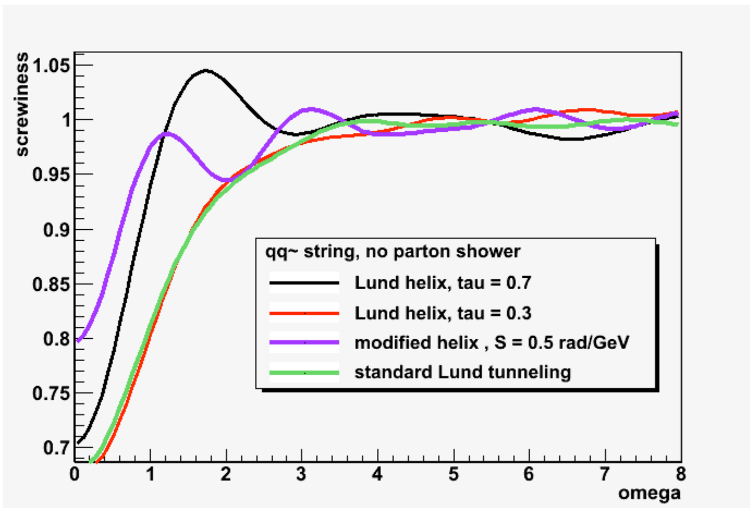
transverse momentum - energy

modified helix





Helix: phenomenology



Not much effect expected in the screwiness measure for modified helix string …. ?

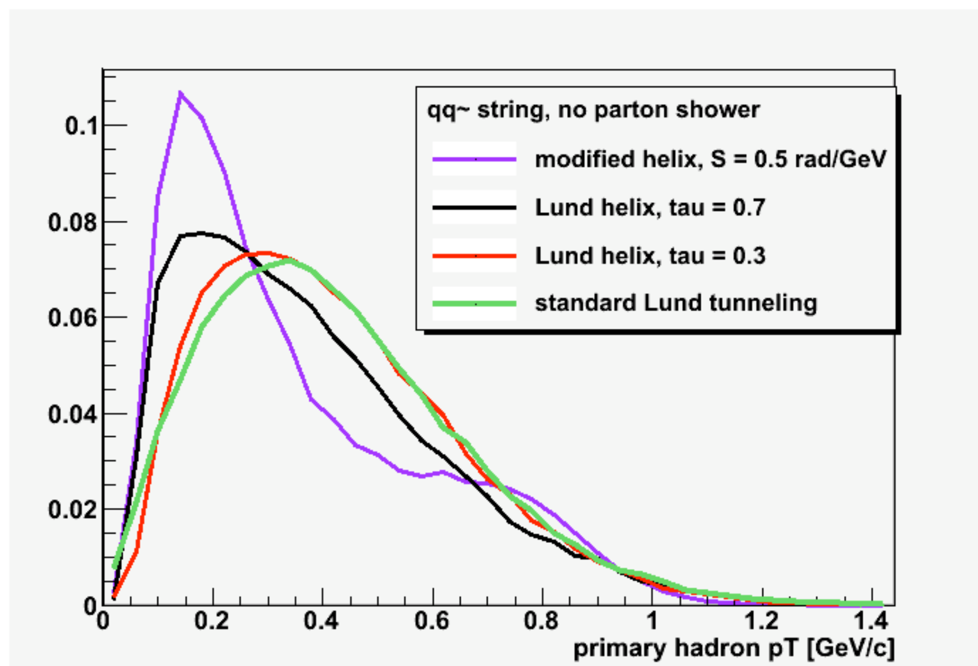
(further diluted by parton shower)

Inclusive pT spectra :

-> bump at pT~0.5 GeV expected !

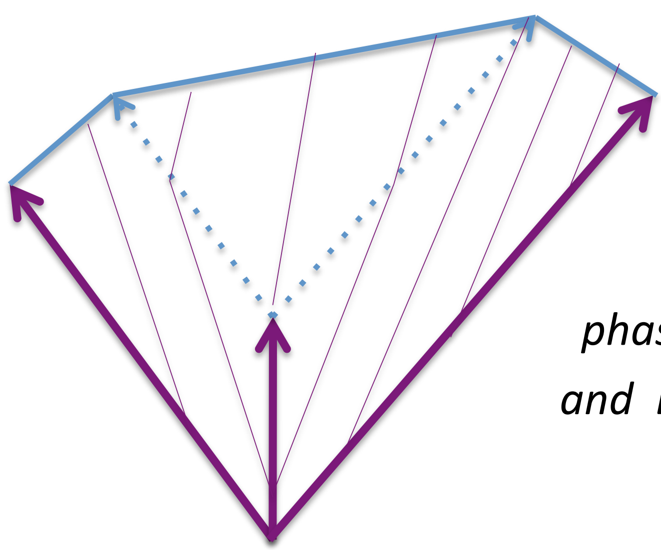
(ex.: helix radius 0.4 ± 0.1 GeV/c, helix winding 0.5 rad/GeV)

Lund helix shows similar tendency (in already excluded region ..?)



Modified helix: implementation

E-pT correlation implemented in PYSTRF routine (Pythia6*) on iteration basis.
The real difficulty resides in treatment of hard gluon kink:



helix phase difference between qq~ endpoints

$$\Delta\phi = S\,\Sigma\,M_{ij}$$

sum runs over all string pieces(*)

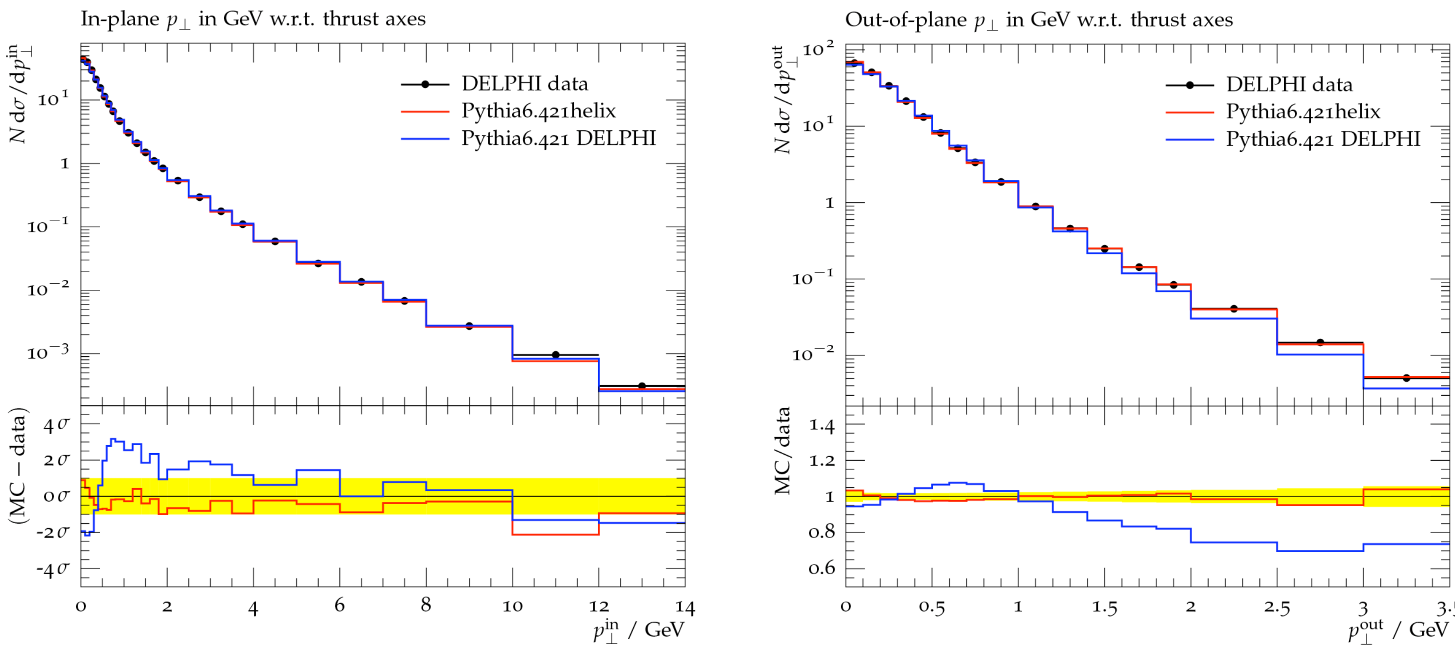
phase at a given point given by initial conditions and E_L / E_R fraction in corresponding string piece

**This is not feasible in case of original Lund helix : gluon kink represents a singularity in helix phase – how to deal with it ?*

Modified helix: comparison with data (tuning)

The modified helix model in combination with 'pT-ordered' parton shower provides much better description of LEP inclusive pT:

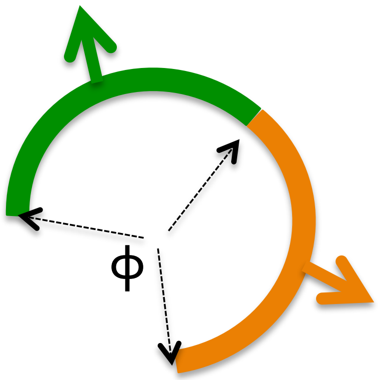
Best fit to pT inclusive (more info in backup slides)



This should translate into better description of a jet profile, as well.

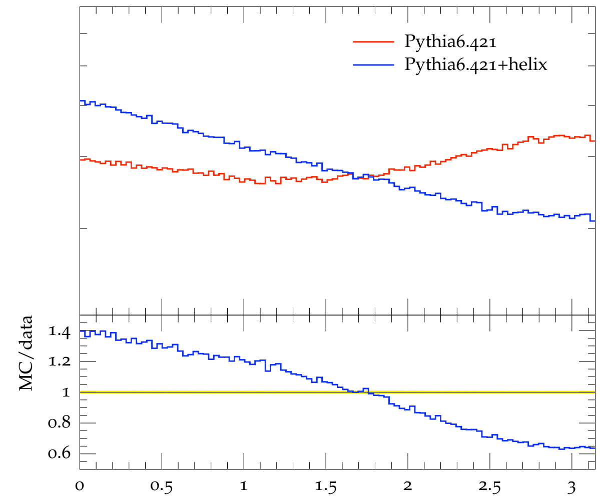
Modified helix: other observables ?

Genuine azimuthal angle correlations are present in the model :



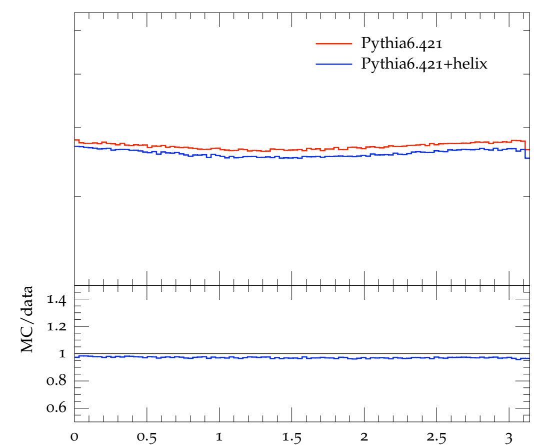
$$\psi_1 - \psi_2 = 0.5\ (\ \phi_{i+2} - \phi_i\ )$$
$$= 0.5 * S * (E_1 + E_2)$$

in c.m.s. of the string



Δψ adjacent primary hadrons

Δψ final hadrons (+- pairs)



Strongly diluted by combinatorial background:

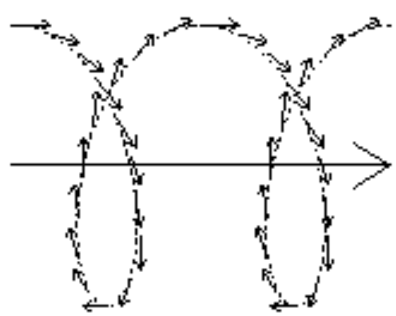
There is some hope to observe these correlations in case short-lived resonances 'remember' the gluon field structure

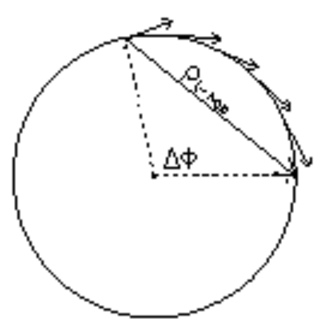
… under investigation

Modified helix parametrization: theory

Is the re-parametrized helix model compatible with theoretical arguments behind the introduction of the helix string ?

YES ! The modified model corresponds to a color ordered stream of gluons with constant k_T and Δy=0. The gluons 'go apart' in the transverse plane (to satisfy the requirement of helicity conservation). The resulting chain of gluon dipoles (with similar mass) forms a regularly spiralling colour field with constant energy density (see next slide for numerical estimates)





Modified helix parametrization: theory

(Based on JHEP09(1998)014. , eq.(7))

Minimal mass of di-gluon dipole allowed to emit additional gluon

$s = \Lambda^2 e^{c} = \Lambda^2 e^{11/6} \approx 0.56\ GeV^2 \quad => \quad M \sim 0.75\ GeV$

(helicity conservation)

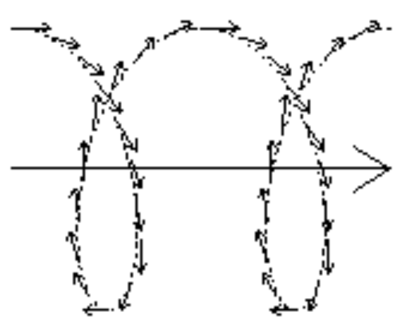
Mass of the resulting dipoles (***after*** *the last emission)*

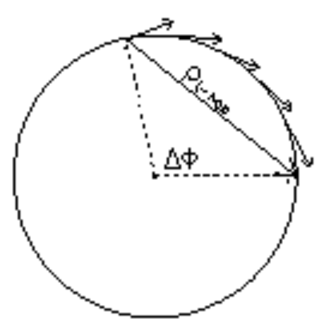
$\boldsymbol{s' \approx 0.19\ GeV^2 \quad => \quad m \sim 0.44\ GeV}$

Tuning *of modified parametrization suggests* $\Delta\phi$ $\boldsymbol{\approx 0.5\ rad/GeV}$

Mass of dipoles for 1 GeV gluons emitted with azimuthal distance 0.45 rad:

~ 0.45 GeV





Summary

This is an attempt to highlight some less understood features of fragmentation model, and to resuscitate the idea of helix-like ordered string color field.

A modification of a helix string model [JHEP09(1998)14] predicts observable effects compatible with LEP data. (LHC data uder investigation)

Modified helix model successfully tuned to LEP (DELPHI) data.
This is a non-trivial result – the helix model effectively removes one degree of freedom from the fragmentation process !

Observables (pT spectra, 2-particle correlations, jet shapes, …) : indirect evidence ?

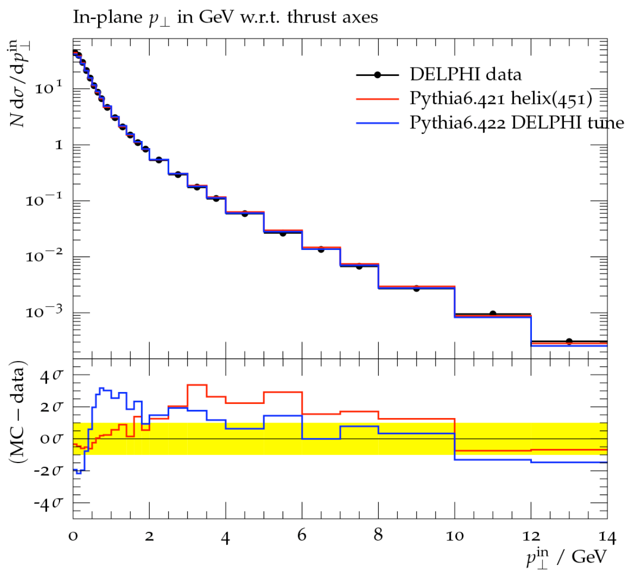
Possible extension to resonance region ? Under investigation … in the absence of convincing theoretical picture, a lot of speculation involved.

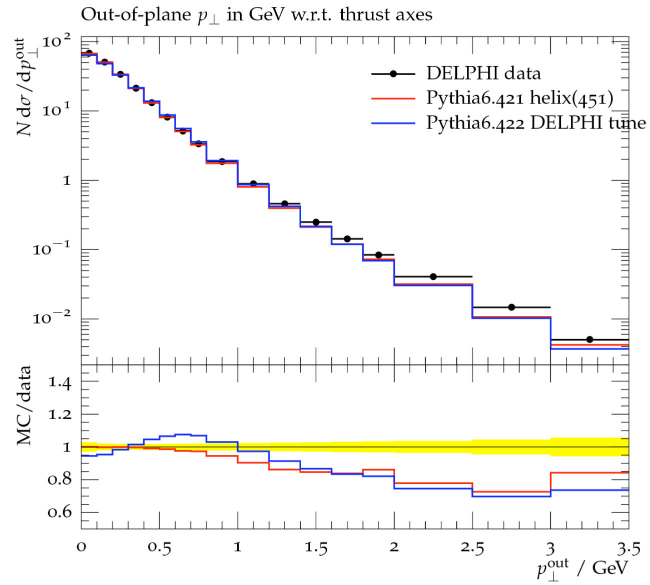
Theoretical picture : possible reconciliation of the different helix parametrizations ?

Acknowledgements to the Rivet/Professor project – a very useful tools !

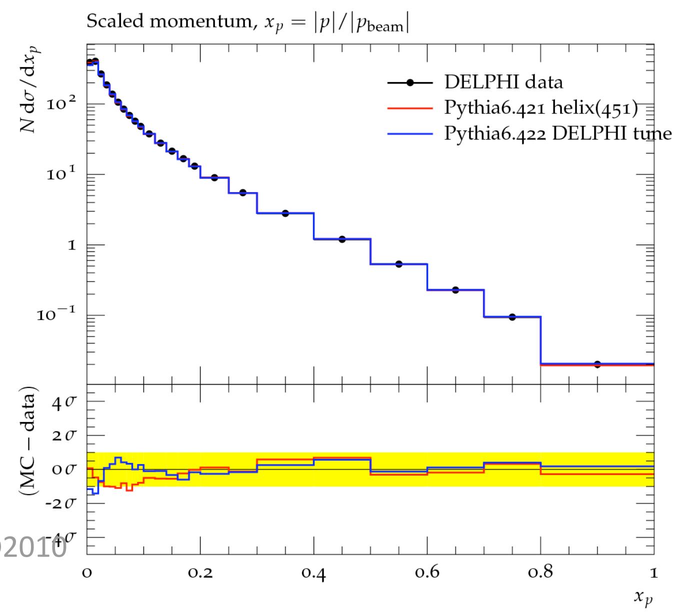
BACK-UP slides

Helix on top of DELPHI tune





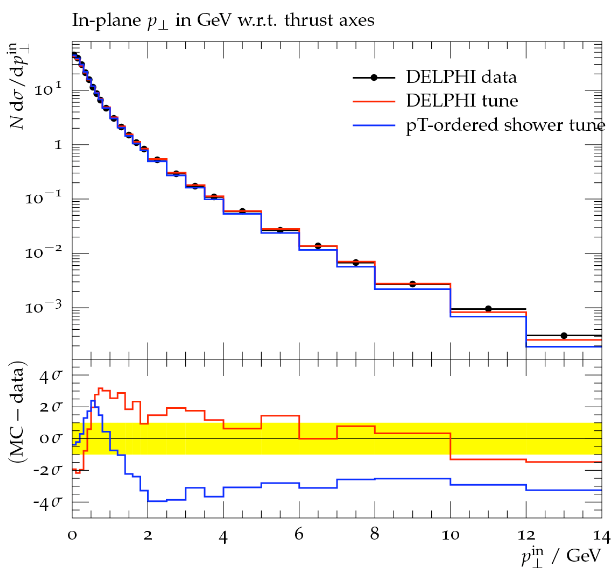
-> fixes low pT region
(>90% of tracks below 1 GeV)
-> retuning not necessary – very little impact on other observables

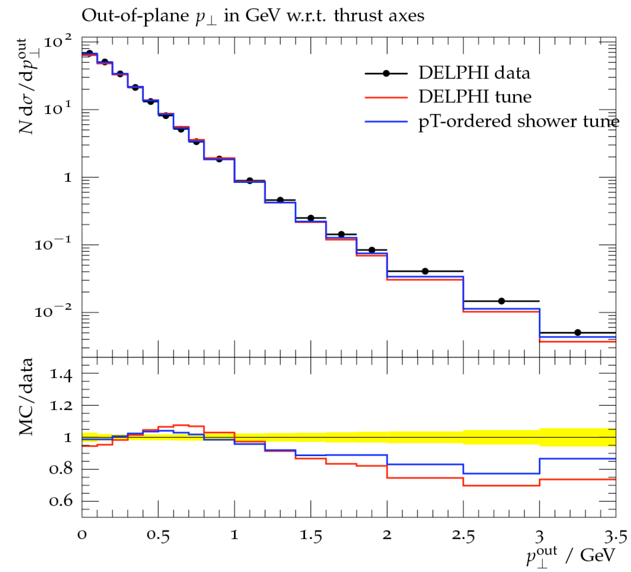


These plots done with:

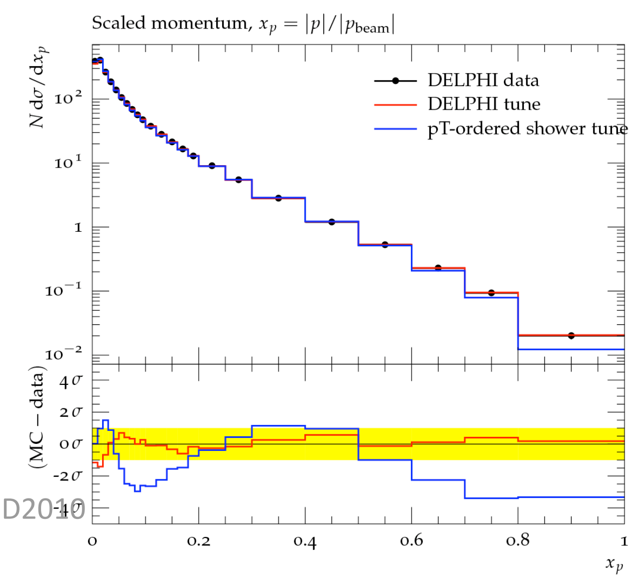
helix radius 0.4±0.1 GeV/c
winding 0.5 rad/GeV

pT ordered shower tune (H.Schulz, ALEPH/DELPHI/OPAL/JADE data) vs. DELPHI tune

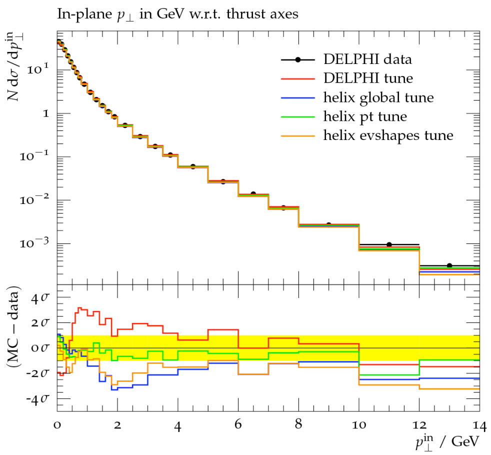


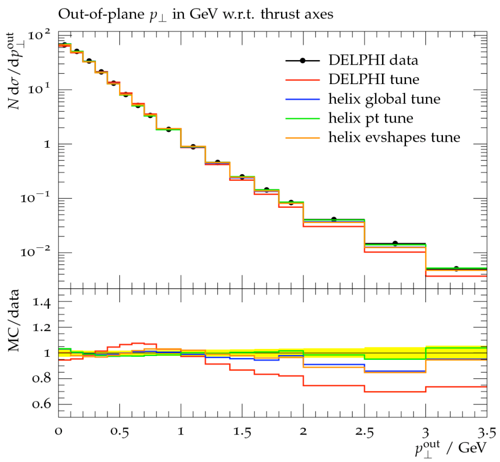


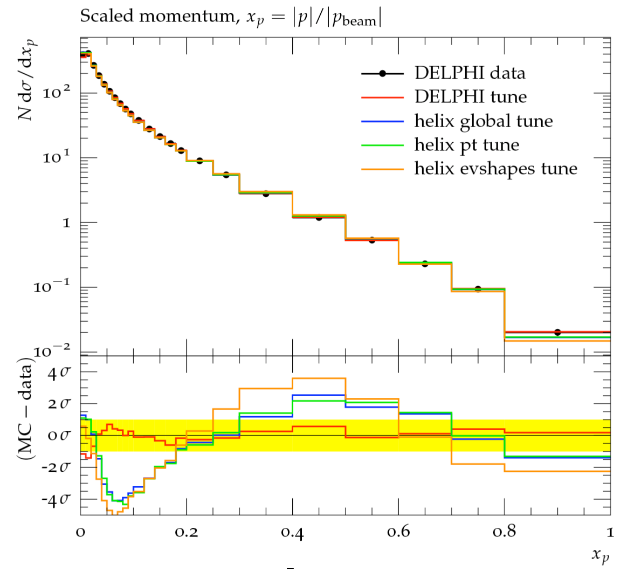
- *pT –in /-out equally underestimated*
- *scaled momentum worse …(!)*
- *Try ARIADNE ? (not available for LHC)*



Helix + pT ordered shower tune
(6 parameters Professor tune, DELPHI data)
vs. DELPHI tune



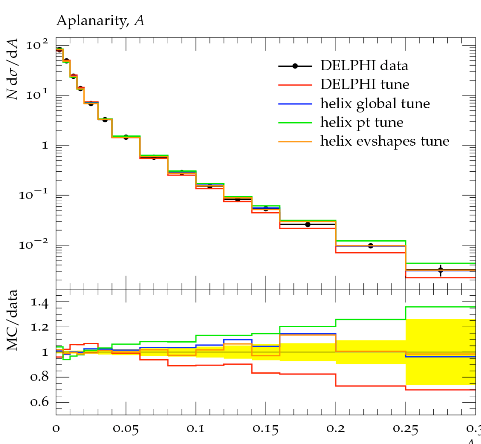


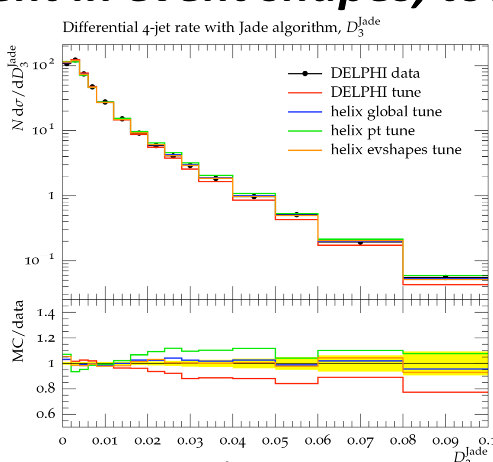


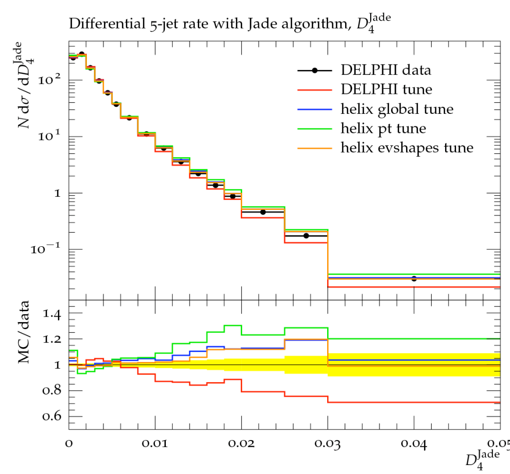
Almost perfect tune of pT

but scaled momentum worse … mostly due to parton shower …

Quite some improvement in event shapes, too:







Helix + pT ordered shower tune
(6 parameters Professor tune, DELPHI data)

Tuned parameters :

	inclusive spectra +event shapes	pT inclusive	event shapes
r PARJ(102)	0.36 +-0.1	0.28 +-0.1	0.42+-0.1
dr PARJ(103)		fixed (0.1)	
S PARJ(104)	0.5 +- 0.5	0.59 +- 0.6	0.38+-0.6
Lund a PARJ(41)	0.08 +- 0.7	0. +- 0.6	0.6+-0.9
Lund b PARJ(42)	0.37 +- 1.	0.77 +- 0.8	0.9+-0.9
L_{QCD} PARJ(81)	0.237+-0.005	0.297 +-0.056	0.23+-0.05
Q_0 PARJ(82)	0.65 +- 0.8	0.41+- 0.5	0.63+-0.9
Goodness of fit	1.8	1.3	0.8
N.d.f.	754	124	457

Only helix 'radius' and Lambda$_{QCD}$ realy constrained => another iteration needed to study softer dependence (S, Lund a,b , …)

Helix string & short lived resonances

Some hope to discover genuine, helix-string induced, azimuthal angle correlation, in case the short-lived resonances 'remember' gluon field structure

-> enhanced signal (primary + decay products)

-> polarized decay ? (2 degrees of freedom removed from 1-> 2 body decay)

Rho resonance enhanced helix signal in pT

(900 GeV pp non-diffractive minimum bias)